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Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume XI. Glass Industry Report

Arthur D. Little, Inc, Cambridge, Mass.

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16. ABSTRACT

This study assesses the likelihood of new process technology and new practices being introduced by energy intensive industries and explores the environmental impacts of such changes.

Specifically Vol. XI deals with the glass industry and examines five alternatives: (1) coal gasification, (2) direct coal firing, (3) electric melting, (4) coal, hot gas regeneration, and (5) batch preheating in terms of their impact on relative process economics and their environmental/energy consequences. Vol. III-X and XII-XV deal with the following industries: iron and steel, petroleum refining, pulp and paper, olefins, ammonia, aluminum, textiles, cement, chlor-alkali, phosphorus and phosphoric acid, copper and fertilizers. Vol. I presents the overall summation and identification of research needs and areas of highest overall priority. Vol. II, prepared early in the study, presents and describes the overview of the industries considered and presents the methodology used to select industries.

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Vol. XI. Glass Industry Report

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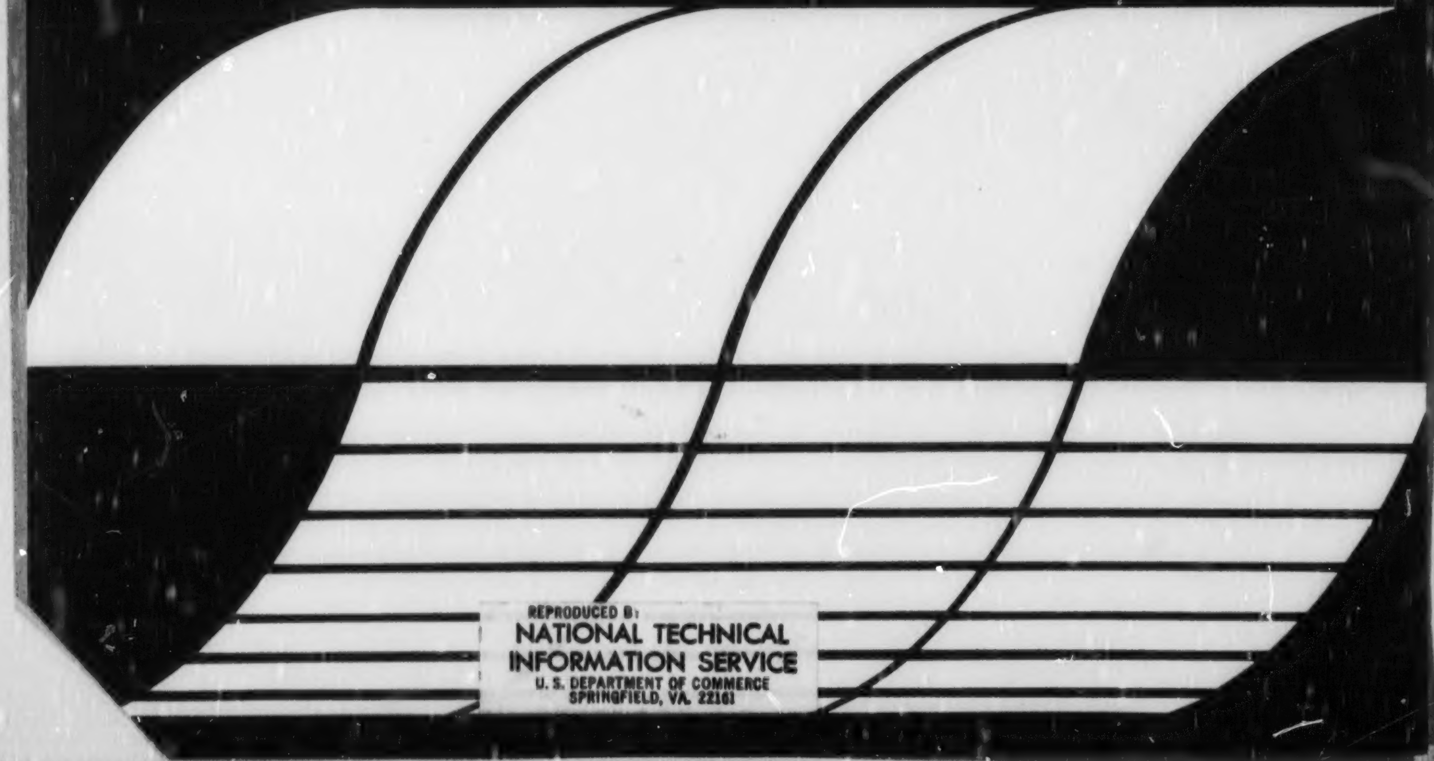

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EPA-600/7-76-034k
December 1976

ENVIRONMENTAL CONSIDERATIONS OF SELECTED ENERGY CONSERVING MANUFACTURING PROCESS OPTIONS

Volume XI

GLASS INDUSTRY REPORT

EPA Contract No. 68-03-2198

Project Officer

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study, consisting of 15 reports, identifies promising industrial processes and practices in 13 energy-intensive industries which, if implemented over the coming 10 to 15 years, could result in more effective utilization of energy resources. The study was carried out to assess the potential environmental/energy impacts of such changes and the adequacy of existing control technology in order to identify potential conflicts with environmental regulations and to alert the Agency to areas where its activities and policies could influence the future choice of alternatives. The results will be used by the EPA's Office of Research and Development to define those areas where existing pollution control technology suffices, where current and anticipated programs adequately address the areas identified by the contractor, and where selected program reorientation seems necessary. Specific data will also be of considerable value to individual researchers as industry background and in decision-making concerning project selection and direction. The Power Technology and Conservation Branch of the Energy Systems-Environmental Control Division should be contacted for additional information on the program.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

EXECUTIVE SUMMARY

In a ranking of the energy intensive industries in the United States (see Table ES-1), the glass manufacturing industry is one of the most significant with a ranking of 9 out of 13. Based on technology, product markets and energy consumption, the glass manufacturing industry is viewed as consisting of four major segments: flat glass, ~66 x 10^{12} Btu, container glass, ~155 x 10^{12} Btu, pressed and blown glass, ~67 x 10^{12} Btu, and glass fiber, ~53 x 10^{12} Btu. In total the 1972 industry shipments were valued at over $4 billion from approximately 400 plants in the United States.

Of the six forms of energy used in the glass industry, natural gas represents by far the major form (70%). In recent years relative fuel oil consumption has increased (~4% in 1971 to 9% in 1972) since fuel oil is a viable alternative to natural gas for melting glass, and the percent of natural gas declined (75% in 1971 down to 70% in 1972) reflecting the supply problem facing the industry. Improvement in energy conservation in the industry can be expected from the introduction of newer industrial practices or processes because of shortages or risk of shortage of natural gas, the primary fuel form in this industry. The use of process modifications and changes in fuel form could result in new or additional pollution loads and therefore require new or additional pollution control techniques.

This study of possible process modifications or the use of alternative fuel forms in the glass industry focused on the unit process of melting since it is in the glass melting function that 60-80% of the total energy for glass manufacturing is consumed, and it is this area that comes closest to being the same for all segments of the industry. Alternative fuel forms for melting analyzed in this study included coal gasification, direct coal firing, coal hot gas generation, and electric melting. The use of oxygen enrichment and submerged burners were briefly considered. Further, a major process modification, that of batch agglomeration and preheating, was also analyzed. In our analysis, technical feasibility, capital investment cost, operating cost, pollution loads, and the cost of pollution control were the key factors considered in comparing the alternative fuel forms and process modifications with present melting practices using natural gas in a 200 tpd side-port fired, regenerative furnace melting a soda-lime-silica type glass.

In terms of total energy consumed in the melting process, the use of all of the alternative fuel forms investigated requires higher energy input per ton of glass produced and thus is not energy conserving. However, all involve the use of coal, a less critical fuel. Primarily because the alternative fuel forms of coal gasification, coal hot gas generation, and direct

TABLE ES-1

SUMMARY OF 1971 ENERGY PURCHASED IN SELECTED INDUSTRY SECTOR

	Industry Sector	10^{15} Btu/Yr	SIC Code In Which Industry Found
1.	Blast furnaces and steel mills	3.49(1)	3312
2.	Petroleum refining	2.96(2)	2911
3.	Paper and allied products	1.59	26
4.	Olefins	0.984(3)	2818
5.	Ammonia	0.63(4)	287
6.	Aluminum	0.59	3334
7.	Textiles	0.54	22
8.	Cement	0.52	3241
9.	Glass	0.31	3211, 3221, 3229
10.	Alkalies and chlorine	0.24	2812
11.	Phosphorus and phosphoric acid production	0.12(5)	2819
12.	Primary copper	0.081	3331
13.	Fertilizers (excluding ammonia)	0.078	287

(1) Estimate for 1967 reported by FEA Project Independence Blueprint, p. 6-2, USGPO, November 1974.

(2) Includes captive consumption of energy from process byproducts (FEA Project Independence Blueprint)

(3) Olefins only, includes energy of feedstocks: ADL estimates

(4) Ammonia feedstock energy included: ADL estimates

(5) ADL estimates

Source: 1972 Census of Manufactures, FEA Project Independence Blueprint, USGPO, November 1974, and ADL estimates.

firing with pulverized coal all involve higher volumes of gas, the emissions from the glass tank, principally SO_x and particulates, are increased over those from furnaces using natural gas. Consequently the cost of pollution control is estimated to be substantially greater with the use of these alternative fuel forms. The capital cost involved for additional facilities to produce and convert the fuel form and the pollution control indicates that coal gasification and coal hot gas generation may not be economically viable alternatives to the use of natural gas. The use of direct fired coal processes, in addition to somewhat higher capital and operating costs, presents formidable technical problems in terms of glass quality and furnace life.

Electric melting of glass appears to be a viable process from both a technical and economical standpoint. Although the total energy consumed is higher than for natural gas melting (by 12%), when consideration is given to the efficiencies of generation, transmission and distribution of the electric power, and to the energy used in pollution control, a less critical form of energy is utilized. Air emission loads can be considerably lower than for natural gas melting on any of the other coal related fuel forms analyzed.

Utilization of waste heat to preheat the batch prior to introduction into the melting furnace has the potential of reducing the energy consumption of the melting function by approximately 20%. Because of the lower fuel requirement in the melting process the emissions from the furnace and cost of control are reduced. Batch preheating could be used with any of the alternative fuel forms and with effective demonstration of the feasibility of such a system could find broad application in the industry.

Effective air emission control systems for glass melting furnaces have not been established. Regardless of which fuel form is used in the industry some form of effective control will probably be required in the future. Water and solid waste streams are of less significance and few additional streams are introduced in any of the alternative fuel forms or process modifications studied.

This report was submitted in partial fulfillment of contract 68-03-2198 by Arthur D. Little, Inc. under sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 9, 1975 to January 23, 1976.

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Dr. Herbert S. Skovronek, Project Officer, was a valuable resource to us throughout the study. He not only supplied us with information on work presently being done in other branches of EPA and other government agencies, but served as an indefatigable guide and critic as the study progressed. His advisors within EPA, FEA, DOC, and NBS also provided us with insights and perspectives valuable for the shaping of the study.

During the course of the study we also had occasion to contact many individuals within industry and trade associations. Where appropriate we have made reference to these contacts within the various reports. Frequently, however, because of the study's emphasis on future developments with comparative assessments of new technology, information given to us was of a confidential nature or was supplied to us with the understanding that it was not to be credited. Therefore, we extend a general thanks to all those whose comments were valuable to us for their interest in and contribution to this study.

Finally, because of the broad range of industries covered in this study, we are indebted to many people within Arthur D. Little, Inc. for their participation. Responsible for the guidance and completion of the overall study were Mr. Henry E. Haley, Project Manager; Dr. Charles L. Kusik, Technical Director; Mr. James I. Stevens, Environmental Coordinator; and Ms. Anne B. Littlefield, Administrative Coordinator.

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Ammonia:	Mr. John L. Sherff, Principal Investigator Ms. Nancy J. Cunningham Mr. Harry W. Lambe
Aluminum:	Mr. Richard W. Hyde, Principal Investigator Ms. Anne B. Littlefield Dr. Charles L. Kusik Mr. Edward L. Pepper Mr. Edwin L. Field Mr. John W. Rafferty
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ENGLISH-METRIC (SI) CONVERSION FACTORS

To Convert From	To	Multiply By
Acre	$Metre^2$	4,046
Atmosphere (normal)	Pascal	101,325
Barrel (42 gal)	$Metre^3$	0.1589
British Thermal Unit	Joule	1,055
Centipoise	Pascal-second	0.001
Degree Fahrenheit	Degree Celsius	$t_C^\circ = (t_F^\circ - 32)/1.8$
Degree Rankine	Degree Kelvin	$t_K^\circ = t_R^\circ/1.8$
Foot	Metre	0.3048
$Foot^3$/minute	$Metre^3$/sec	0.0004719
$Foot^3$	$Metre^3$	0.02831
$Foot^2$	$Metre^2$	0.09290
Foot/sec	Metre/sec	0.3048
$Foot^2$/hr	$Metre^2$/sec	0.00002580
Gallon (U.S. liquid)	$Metre^3$	0.003785
Horsepower (550 ft-lbf/sec)	Watt	745.7
Horsepower (electric)	Watt	746.0
Horsepower (metric)	Watt	735.5
Inch	Metre	0.02540
Kilowatt-hour	Joule	3.60×10^6
Litre	$Metre^3$	1.000×10^{-3}
Micron	Metre	1.000×10^{-6}
Mil	Metre	0.00002540
Mile (U.S. statute)	Metre	1,609
Poise	Pascal-second	0.1000
Pound force (avdp)	Newton	4.448
Pound mass (avdp)	Kilogram	0.4536
Ton (assay)	Kilogram	0.02916
Ton (long)	Kilogram	1,016
Ton (metric)	Kilogram	1,000
Ton (short)	Kilogram	907.1
Tonne	Kilogram	1,000

Source: American National Standards Institute, "Standard Metric Practice Guide," March 15, 1973. (ANS72101-1973) (ASTM Designation E380-72)

I. INTRODUCTION

A. BACKGROUND

Industry in the United States purchases about 27 quads* annually, approximately 40% of total national energy usage.** This energy is used for chemical processing, raising steam, drying, space cooling and heating, process stream heating, and miscellaneous other purposes.

In many industrial sectors energy consumption can be reduced significantly by better "housekeeping" (i.e., shutting off standby furnaces, better thermostat control, elimination of steam and heat leaks, etc.) and greater emphasis on optimization of energy usage. In addition, however, industry can be expected to introduce new industrial practices or processes either to conserve energy or to take advantage of a more readily available or less costly fuel. Such changes in industrial practices may result in changes in air, water or solid waste discharges. The EPA is interested in identifying the pollution loads of such new energy-conserving industrial practices or processes and in determining where additional research, development, or demonstration is needed to characterize and control the effluent streams.

B. CRITERIA FOR INDUSTRY SELECTION

In the first phase of this study we identified industry sectors that have a potential for change, emphasizing those changes which have an environmental/energy impact.

Industries were eliminated from further consideration within this assignment if the only changes that could be envisioned were:

- energy conservation as a result of better policing or "housekeeping,"
- better waste heat utilization,
- fuel switching in steam raising, or
- power generation.

After discussions with the EPA Project Officer and his advisors, industry sectors were selected for further consideration and ranked using:

---

*1 quad = 10^{15} Btu

**Purchased electricity valued at an approximate fossil fuel equivalence of 10,500 Btu/kWh.

- Quantitative criteria based on the gross amount of energy (fossil fuel and electric) purchased by industry sector as found in U.S. Census figures and on information provided from industry sources. The glass industry purchased 0.31 quads out of the 12.14 quads purchased by the 13 industries selected for study in 1971, or 1% of the 27 quads purchased by all industry (see Table I-1). Of this 0.31 quads 74% is in the most critical form, natural gas.

- Qualitative criteria relating to probability and potential for process change, and the energy and effluent consequences of such changes.

In order to allow for as broad a coverage of technologies as possible, we then reviewed the ranking, eliminating some industries in which the process changes to be studied were similar to those in another industry planned for study. We believe the final ranking resulting from these considerations identifies those industry sectors which show the greatest possibility of energy conservation via process change. Further details on this selection process can be found in the Industry Priority Report prepared under this contract (Volume II). On the basis of this ranking method, the glass industry appeared in eighth place among the 13 industrial sectors listed.

TABLE I-1

SUMMARY OF 1971 ENERGY PURCHASED IN SELECTED INDUSTRY SECTORS

Industry Sector	10^{15} Btu/Yr.	SIC Code In Which Industry Found
1. Blast furnaces and steel mills	3.49(1)	3312
2. Petroleum refining	2.96(2)	2911
3. Paper and allied products	1.59	26
4. Olefins	0.984(3)	2818
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(2) Includes captive consumption of energy from process byproducts (FEA Project Independence Blueprint)

(3) Olefins only, includes energy of feedstocks: ADL estimates

(4) Amonia feedstock energy included: ADL estimates

(5) ADL estimates

Source: 1972 Census of Manufactures, FEA Project Independence Blueprint, USGPO, November 1974, and ADL estimates.

C. CRITERIA FOR PROCESS SELECTION

In this study we have focused on identifying changes in the primary production processes which have clearly defined pollution consequences. In selecting those to be included in this study, we have considered the needs and limitations of the EPA as discussed more completely in the Industry Priority Report mentioned above. Specifically, energy conservation has been defined broadly to include, in addition to process changes, conservation of energy or energy form (gas, oil, coal) by a process or feedstock change. Natural gas has been considered as having the highest energy form value followed in descending order by oil, electric power, and coal. Thus, a switch from gas to electric power would be considered energy conservation because electric power could be generated from coal, existing in abundant reserves in the United States in comparison to natural gas. Moreover, pollution control methods resulting in energy conservation have been included within the scope of this study. Finally, emphasis has been placed on process changes with near-term rather than long-term potential within the 15-year span of time of this study.

In addition to excluding from consideration better waste heat utilization, "housekeeping," power generation, and fuel switching, as mentioned above, certain options have been excluded to avoid duplicating work being funded under other contracts and to focus this study more strictly on "process changes." Consequently, the following have also not been considered to be within the scope of work:

- Carbon monoxide boilers (however, unique process vent streams yielding recoverable energy could be mentioned);
- Fuel substitution in fired process heaters;
- Mining and milling, agriculture, and animal husbandry;
- Substitution of scrap (such as reclaimed textiles, iron, aluminum, glass, and paper) for virgin materials;
- Production of synthetic fuels from coal (low- and high-Btu gas, synthetic crude, synthetic fuel oil, etc.); and
- All aspects of industry-related transportation (such as transportation of raw material).

D. SELECTION OF GLASS INDUSTRY PROCESS OPTIONS

Within each industry, the magnitude of energy use was an important criterion in judging where the most significant energy savings might be realized, since reduction in energy use reduces the amount of pollution generated in the energy production step. Guided by this consideration, candidate options for in-depth analysis were identified from the major energy consuming process steps with known or potential environmental problems.

After developing a list of candidate process options, we assessed subjectively

- pollution or environmental consequences of the process change,
- probability or potential for the change, and
- energy conservation consequences of the change.

Even though all of the candidate process options were large energy users, there was wide variation in energy use and estimated pollution loads between options at the top and bottom of the list. A modest process change in a major energy consuming process step could have more dramatic energy consequences than a more technically significant process change in a process step whose energy consumption is rather modest. For the lesser energy-using process steps process options were selected for in-depth analysis only if a high probability for process change and pollution consequences was perceived.

Because of the time and scope limitations for this study, we have not attempted to prepare a comprehensive list of process options or to consider all economic, technological, institutional, legal or other factors affecting implementation of these changes. Instead we have relied on our own background experience, industry contacts, and the guidance of the Project Officer and EPA advisors to choose the following candidates for study in the glass industry:

1. Coal Gasification
2. Direct Coal Firing
3. Electric Melting
4. Coal, Hot Gas Generation (COHOCG)
5. Batch Preheating
6. Oxygen Enrichment of Natural Gas
7. Submerged Burners
8. Electric Boosting Melting
9. Recycle Cullet

After discussion with the EPA Project Officer, his advisors, and industry representatives, we chose the first five from this list for analysis because:

- Four of the first five systems involved a fundamental change in fuel form from a critical fuel to a less critical fuel.
- Electric boosting melting is a current practice in a large number of glass melting installations at the present time.

- Submerged burners as presently conceived are known to have adverse effects on glass quality and technical feasibility is very questionable. (Battelle Laboratories, 1974)

- The use of recycle cullet from municipal waste streams involves a serious question of a socio-economic nature as well as the technical feasibility of collection and separation. No new information could be generated in this study to resolve these questions.

- Oxygen enrichment is considered a modification of present techniques, thus is discussed qualitatively based on available information.

In this study, the glass industry description is based on 1972, the latest representative year for the industry for which we had good statistical information. Recognizing that capital investments and energy costs have escalated rapidly in the past few years and have greatly distorted the traditional basis for making cost comparisons, we developed costs representative of the first half of 1975, using constant 1975 dollars for our comparative analysis of new and current processes.

II. FINDINGS AND CONCLUSIONS

A. FINDINGS

On the basis of the analysis of technical, energy consumption, pollution, and economic factors for a typical present day natural gas-fired glass melting operation and potential alternative melting processes, the principal findings are as follows:

1. In the manufacturing of glass products, the melting unit process is by far the most energy intensive. Natural gas, because of its ease of handling, cleanliness, consistency and, until recently, its availability and low cost, is the primary energy form used in the United States to melt glass.
2. Of the alternatives considered, coal gasification, hot gas generation, direct coal firing and electric melting all involve the use of a less critical form of fuel - coal. The total energy consumption with each of these alternative glass melting unit processes is greater than with natural gas (Table II-1).
3. At present, there are no proven technologies for the effective control of air emission from a glass tank fired with natural gas or any of the alternative fuel forms listed in finding 2. Effective scrubbing and filter systems have not yet been demonstrated.
4. Coal gasification, hot gas generation and direct coal firing are estimated to involve significant additional capital investment cost and increased operating cost per ton of glass produced. Direct coal firing adds the least investment and cost, while coal gasification increases both investment and manufacturing cost per ton the greatest amount (Table II-2).
5. The use of the coal-based alternatives is expected to result in increases in the amount of air emissions from the glass melting process because of the greater gas volumes and additional airborne pollutants from coal combustion. Additional solid waste and water effluent streams also are involved in the separate processes of coal gasification and hot gas generation and require further pollution controls (Table II-3). Cost of pollution control for these processes could be more economically significant than for the glass making process.

TABLE II-1

SUMMARY OF ENERGY CONSUMPTION: GLASS MELTING UNIT PROCESS
(Basis: 200 tpd of glass)

Energy Source	Natural Gas Firing	Direct Coal Firing	Coal Gasification	Coal-Fired Hot Gas Generation	Electric	Particle* Agglomeration
ENVIRONMENTAL						
Electric Power						
kWh/ton	24.48	26.85	46.71	30.82	1.78	14.79
Fuel Equivalent (10^6 Btu/ton)	0.25	0.28	0.49	0.32	0.02	0.16
Fuel (10^6 Btu/ton)	0.32	0.37	0.41	0.45	0.01	0.21
Total Fuel Equivalents for Environmental Control (10^6 Btu/ton)	0.57	0.65	0.90	0.77	0.03	0.37
PROCESS						
Melting (10^6 Btu/ton)	6.8	6.8	8.4	8.4	8.2	5.5
Controls (10^6 Btu/ton)	0.2	0.2	0.2	0.2		0.2
Total Fuel Equivalents for Melting Process (10^6 Btu/ton)	7.0	7.0	8.6	8.6	8.2	5.7
Total Energy Consumption (10^6 Btu/ton)	7.57	7.65	9.50	9.37	8.23	6.07

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*Preheating with side port regenerative furnace.

TABLE II-2

SUMMARY OF INVESTMENT AND OPERATING COST FOR THE BASE CASE* AND ALTERNATIVE MELTING UNIT FUEL PROCESSES AND PROCESS MODIFICATIONS

	Facilities		Air Pollution Control		Water Pollution Control		Solid Waste Control		
Melting Unit Process	Glass Furnace	Auxiliary Installation	Glass Furnace	Auxiliary Installation	Glass Furnace	Auxiliary Installation	Glass Furnace	Auxiliary Installation	Total
Natural Gas Firing									
Investment ($000)	1,404	—	1,136	—	95	—	—	—	2,635
Operating Cost***$/ton	72.67	--	7.09	—	0.64	—	0.01	—	80.41
Coal Gasification									
Investment ($000)	1,404	1,380	1,231	1,066	95	—	—	—	5,176
Operating Cost $/ton	91.74		7.68	6.00	0.64	2.50	6.01	0.24	114.81
Direct Coal Firing									
Investment ($000)	1,404	355	1,420	—	192	—	—	--	3,371
Operating Cost $/ton	67.17		9.14	—	1.38	—	0.01	0.21	77.91
Coal-Fired Hot Gas Generation									
Investment ($000)	1,404	1,560	1,420	--	95	—	—	—	4,479
Operating Cost $/ton	85.17		8.93	—	0.64	—	0.01	0.28	95.03
Electric Melting									
Investment ($000)	1,624	—	304	(650)**	95	—	—	—	2,673
Operating Cost $/ton	76.02		2.12	(2.57)**	[illegible].64	—	0.01	(0.18)**	81.54
Batch Preheat with/Natural Gas Firing									
Investment ($000)	1,404	500	951	—	95	—	—	—	2,950
Operating Cost $/ton	72.94		5.18	—	0.64	—	0.01	—	78.77

*Base Case - 200-tpd, Natural Gas-Fired, Side Port, Regenerative Furnace. Costs Reflect only Melting Cost.

**Cost of pollution control at power generation station prorated to glass plant.

***Operating cost $/ton = production cost plus pre tax return on investment @ 20%.

TABLE II-3

AIR, WATER, AND SOLID WASTE STREAMS FROM BASE CASE AND ALTERNATIVE FUEL SYSTEMS AND PROCESS MODIFICATIONS

	Air Emission		Water Effluent Streams		Solid Waste	
Melting Unit Fuel Process	**Glass Furnace**	**Auxiliary Installation**	**Glass Furnace**	**Installation**	**Glass Furnace**	**Installation**
Natural Gas Firing	NO_x, SO_x, particulates	—	Scrubber purge	—	Dust from fabric filter Scrubber sludge	—
Coal Gasification	Increased NO_x, SO_x, particulates from melt & batch	Sulfur removal* from incoming gas stream	Scrubber purge	Sulfur rec. purge	Dust from filter Scrubber sludge	Ash Sulfur rec.
Direct Coal Firing	Increased NO_x, SO_x, particulates	—	Scrubber purge	—	Dust from fabric filter, sludge from scrubbers	Ash
Coal-Fired Hot Gas Generation	Increased NO_x, SO_x, particulates	—	Scrubber purge	—	Dust from filter Scrubber sludge	Ash Limestone
Electric Melting	Reduced NO_x, SO_x, particulates	SO_2 power** plant	Scrubber purge	—	Dust from fabric filter Scrubber sludge	Ash Power Generation Plant
Batch Preheat with Natural Gas Firing	Reduced NO_x, SO_x, particulates	—	Scrubber purge	—	Dust from fabric filter Scrubber sludge	—

*Gas from producer subjected to sulfur removal before entering glass furnace.

**Indicates air and water streams at power generating station.

TABLE II-4

QUALITATIVE COMPARISON OF THE ALTERNATIVE PROCESS ECONOMICS, ENERGY, AND ENVIRONMENTAL IMPLICATIONS

(all relative to base case)

Factor	Coal Gasification	Coal Hot Gas Generator	Direct Coal Firing	Electric Melting	Batch Preheat
Process	Higher capital investment	Higher capital investment	Increased investment cost	Similar investment requirements	Similar investment requirements
Economics	Higher operating cost	Increased operating cost	Slightly greater operating cost	Slightly greater operating cost	Slightly lower operating cost
Energy	Pollution control energy consumption higher	Increased energy consumption in pollution control equipment	Slightly higher energy consumption for pollution control	Greatly reduced energy consumption for pollution control	Reduced energy consumption for pollution control
	Increased energy for melting due to inefficiency in system	Increased energy for melting	Comparable energy required in melting	Increased energy requirements for melting due to loss in transmission and distribution	Reduced energy requirements for melting
Environment	Increased air emission from glass furnace but same species	Higher air emission from glass furnace	Higher air emission from glass furnace	Greatly reduced air emission from glass furnace	Reduced air emission from glass furnace
	Slightly increased water effluent	Additional solid waste stream (ash and limestone)	Additional solid waste stream (ash)	Emission & solid waste streams transferred to electric power generation source	
	New solid waste stream (ash & sulfur)				

6. The electric melting process appears to be a technically and economically competitive alternative. Air emissions from the glass furnace are substantially reduced in volume in electric melting and therefore, the cost of pollution control required is much less. However, the use of electricity as an alternative fuel form increases the magnitude of pollution emissions at the power generating plant.

7. Process modification to utilize heat from the melting furnace for preheating the batch reduces overall energy consumption. Air emissions from the glass furnace are reduced due to the lower fuel requirement and the consequent lower exhaust gas volume. Pollution control costs are correspondingly lower for the glass furnace. The batch preheat process could be utilized with all the analyzed alternative fuel forms except electric melting (Table II-4).

B. CONCLUSIONS

1. There are no proven systems for controlling air emission from glass furnaces. Economical and effective techniques for removal of sulfur and fine particulate from stack gases are required.

2. Due to the lack of availability and increased cost of natural gas, alternative fuel processes, principally coal-based, will be considered. All the coal-based alternatives - i.e., coal gasification, hot gas generation, and direct coal firing -- greatly increase the emission loads from the glass furnace and will require larger and more expensive systems.

3. Because of substantial investment cost and increased operating cost, processes such as coal gasification are not economically attractive alternatives to natural-gas-fired furnaces at this time. Although economically attractive, direct firing with coal is presently beset with serious technical problems which are related to the effect of the ash on glass furnace refractories and on glass quality; as such, its viability as an alternative is uncertain.

4. Electric melting undoubtedly will find increased use in glass melting. Considerably lower gas volumes reduce the load on air emission control requirements.

5. A form of batch preheating can be an effective way to reduce fuel requirements and, consequently, gas exhaust volume and pollution control costs.

6. Emission species from the glass furnace, with few exceptions, remain essentially the same regardless of which fuel form or process modification is used. By and large, the volume of air emission from the furnace increases for all coal-based alternatives whereas electric melting and batch preheat reduce exhaust volume.

7. Additional solid waste and water streams created by alternative processes, although involving increased capital and operating costs, appear to be amenable to existing technology.

C. IMPACT OF EPA POLICIES ON FUTURE CHOICE OF ALTERNATIVES

1. Regulations relating to environmental quality of effluents and emissions from coal generation of electricity will have impacts on the availability and cost of power for melting glass.

2. Future air emission standards for glass furnaces relating to NO_x, SO_x, and particulates will determine the costs of control. All coal-related alternative fuels increase emission. The choice of alternatives would be influenced by these added costs, and the potential high cost of pollution control could deter further development.

3. Trends toward electric melting and batch preheating process modification could depend upon the specifics of any proposed air emission standards.

D. PRACTICES/PROCESSES REQUIRING ADDITIONAL RESEARCH

1. A proven system to control glass furnace emissions of SO_x and particulates must be developed if cost-effective pollution control is to be obtained. Such a system is required if any of the coal-related processes is to be utilized.

2. The feasibility of a batch preheating process modification needs to be demonstrated to stimulate implementation of this technique for energy conservation and pollution reduction. The technical and economic feasibility of a preheat-agglomerate process modification is the subject of EPA's RFP No. DU-75-A291.

3. Demonstration of the technical feasibility of producing quality glass with economic furnace operation and life using direct firing of pulverized coal would aid in conserving energy by utilizing the less critical form of fuel with a minimum of intermediate steps and their cost in dollars and energy.

III. INDUSTRY OVERVIEW

The U.S. glass manufacturing industry can be viewed as comprising four major segments based on its technology, products and markets, i.e., flat glass, container glass, pressed and blown glass, and glass fibers, and a fifth segment, i.e., the products of purchased glass. The latter segment is not an integrated glass-producing segment because it does not melt glass; it only performs finishing operations. Compared to the four major segments the products from the purchased glass segment are low consumers of energy and will not be considered in this study. Handmade glassware manufacturing is also excluded from the analysis.

In total, the industry shipments in 1972 were valued at more than $4 billion and were from approximately 400 plants in the United States. The total industry employment is estimated to be 15,000. The largest single segment is glass containers, which probably accounts for 60% of the glass tonnage produced in this country. Of the total value of products, the glass container segment represents 51%, wool and textile fibers 18%, pressed and blown ware 17%, and flat glass 14% (Department of Commerce, 1972).

In general, the companies in the glass industry participate in one and perhaps two segments but rarely does a single company have broad participation in more than two segments. In the flat glass and fiber glass segment, the industry is concentrated in relatively few firms; 7 companies dominate the flat glass segment and three companies produce 80-90% of the fiber glass in the United States. The concentration is less intensive in the glass container segment, although the eight largest of its 30 firms probably produce 75-80% of the product.

The markets for the industry are broad and very diverse. Therefore, generalizing on the industry growth is difficult. Flat glass shipments are heavily dependent on the automotive and construction industry. Some pressed and blown ware are more closely tied to consumer spending for television, lighting, and household goods. Wool fiber glass markets are dominated by construction, both residential and commercial, whereas textile fibers are used in marine, automotive, and construction products. The container glass market is highly influenced by the beverage market, where glass competes with aluminum and steel.

The future growth in the total glass industry is expected to continue at much the same rate as its historic rate, which has been slightly less than the GNP. The bulk of the glass production in the United States is concentrated in the East North Central, Middle Atlantic, and Pacific regions. The major glass producing states are Illinois, Ohio, Pennsylvania, New York, West Virginia, New Jersey, and California.

In the glass industry the predominant energy sources are natural gas and electricity. In 1972, in the four major segments natural gas accounted for 70% of the energy consumed by the industry; electricity, 20%. The remainder was largely fuel oil. There are differences in the patterns of energy use within each segment, but the basic fact is that natural gas is the predominant fuel used to melt glass; and the melting step is the major energy consumer in the entire glass manufacturing process. There have been no major shifts in fuel consuming patterns in recent years. However, natural gas has been available only on an interruptible basis and standby fuel, principally propane and oil, is necessary. Many plants now have provisions for using oil, particularly in the winter months in New England and the Atlantic states.

IV. COMPARISON OF CURRENT AND ALTERNATIVE PROCESSES

A. INTRODUCTION

1. Process Options Analyzed

In the analysis of the glass manufacturing process, two factors indicate the likelihood of process changes that might be instituted by the industry because of energy considerations. First, the melting process is by far the most significant energy consuming unit process in glass manufacturing. Second, natural gas is the predominant fuel for firing the melting furnace. Since the availability of natural gas has been a major problem for glass companies for the past year and a half, alternative fuels, principally oil, have been required to maintain production.

Therefore, alternatives to natural gas-fired melting processes are of prime importance to the future and viability of the industry. The use of fuel oil has and will continue to be an alternative in present furnaces for melting. However, it is certainly not a panacea for the industry's energy problems since the availability, cost, and supply of oil is certainly not assured and will be influenced by world political and economic factors. An even greater uncertainty would be an attempt to rely on propane for anything more than a standby fuel. Propane's availability is limited and its cost high. Basically the only fuel alternative that reduces the long-term risk and uncertainties associated with the present fuels is coal - in one form or another.

Therefore, alternatives based on coal as the primary fuel were given the highest priority in this study. The approaches that were considered are direct firing with coal, coal gasification, coal-fired hot gas generation, and electricity based on generation from coal-fired power plants. In addition, one process modification which is aimed at improving efficiency of utilizing energy in the melting process was considered. The glass melting furnace as it has evolved is not a highly energy-efficient operation: about 19% of energy input to the furnace is consumed only in melting the glass. If the temperature of the batch raw materials and cullet could be raised to the temperature required for "fining" by a more efficient process, the overall energy savings could be significant. Utilizing waste furnace heat, one approach would be to preheat the batch, preferably in an agglomerate form to reduce dusting and improve heat transfer prior to adding the batch to the furnace.

By and large, a number of modifications of glass furnaces can be made, particularly in their operating parameters, to improve efficiency and reduce fuel consumption: e.g., reduction of structural losses (insulation), reduction of stack losses, improved port geometry, use of oxygen (see Appendix C), etc. Many of these are now common industry practice and energy conservation may be achieved in situations in which no major process modifications have to be made.

2. Basis of Production Cost Analysis

The costs of raw materials were based upon delivered costs in the first half of 1975 at the glass plant.

The energy costs for coal and natural gas were based upon the prices paid in March 1975 by electric utilities for the East North Central (ENC) region, which contains the greatest portion of container glass manufacturing plants. We have found that such prices are consistent with prices reported by SIC sector in the 1972 Census and escalated by fuel cost indices to 1975. But the gas and electric utility industries are largely regulated and the 1975 (first half) price would not be indicative of what a new plant built upon a greenfield site would have to pay for energy. The cost of natural gas for such new facilities may well equal that of oil.

The cost of cooling water was based upon 3¢ per thousand gallons and the cost of process water was based upon 20¢ per thousand gallons.

The cost of labor was based upon wage rates published by the Bureau of Labor Statistics for March 1975 by industry sector and region.

The costs of maintenance, both labor and supplies, were taken as a percentage of the initial investment costs.

Labor overhead accounting for fringe benefits such as vacations, holidays, sick pay, hospitalization, insurance, etc., as well as overtime pay, was taken at 35% of total labor wages.

The miscellaneous variable costs, including such items as minor batch ingredients, supplies and services, were estimated as a percentage of the raw materials cost. The fixed costs include plant overhead, such as the front offices, accounting, plant services (e.g., guards, cafeterias), and other plant costs which might not be allocated to the production sector. Local taxes, including city taxes, county taxes and state taxes paid normally on the valuation of the property, and insurance were taken as 2% of the initial capital investment. Depreciation was taken on a straight line basis over a 14-year period. Also included in the total cost is an ADL-estimated pretax return on investment, which was taken as 20% of the fixed capital investment. This figure is allocated to one ton of product and assumes that the plant is operating at 100% capacity.

B. CURRENT PROCESS (BASE CASE)

1. Process Description

In the U.S. glass industry approximately 90% (Arthur D. Little, Inc., 1975) of all glass is melted in regenerative furnaces. These furnaces are fired with natural gas as the primary fuel. Presently, two types of regenerative furnaces are used: side port and end port. Basically they perform quite similarly. Because of its ability to incorporate a greater checkers volume than the end port furnace, the side port regenerative furnace has higher pull rates; therefore, in this country more glass is melted in this type of furnace. In terms of energy consumption per ton of glass melted, initially the end port furnace consumes less energy, but subsequently the checker volume decreases through plugging, and over the life of the furnace melting efficiency becomes somewhat less than that of the side port furnace.

Presently, in the United States more than 50 different glass compositions are being melted. However, approximately 95% of the total tonnage shipped consists of soda-lime glass. This glass contains about 72% silica, 14% soda, and 9% calcia by weight (Arthur D. Little, Inc., 1975; and Tooley, 1974).

In essence, glass melting in the United States may be represented by the melting of soda-lime glass in a natural gas-fired, side port, regenerative furnace.

On the basis of our experience, to simplify comparison with alternative processes for melting glass, we have fixed a set of operating conditions for what may be termed the base case (Table IV-1) so we can compare alternative processes to the base case in terms of changes in capital investment and operating costs, differences in degree and type of pollutants, and changes in energy melting efficiency.

A natural gas-fired, side port, regenerative furnace is quite consistent with normal practice. On the basis of conversations with glass manufacturers and glass tank designers, we chose a pull rate of 200 tons per day (tpd). Soda-lime glass was chosen because it accounts for the bulk of glass being manufactured in the United States. Feed rate was based upon typical soda-lime formulations, which indicated that 1200 pounds of raw materials are required to produce 1000 pounds of glass, hence at a 200 tpd pull rate, 200 x 1200/1000 or 240 tpd of raw material are required. To establish fuel prices and wages, as well as other costs, an East North Central location was chosen because the area has the largest single concentration of glass manufacturing plants. Finally, an estimated overall efficiency of 90% was taken as the industry standard, hence at a pull rate of 200 tpd, the amount of saleable glass would be about 180 tpd. These assumptions are consistent with industry practice, and any variation in actual practice from these operating assumptions will not affect any of our conclusions.

TABLE IV-1

OPERATING ASSUMPTIONS FOR BASE CASE

- Furnace Type - Side port, regenerative
- Fuel - Natural gas
- Glass Type - Soda-lime
- Plant Location - East North Central
- Pull Rate - 200 tons per day
- Feed Rate - 240 tons per day
- Efficiency - 90%, or 180 tons per day

The major raw materials which make up a soda-lime glass are silica sand, feldspar, dolomite, limestone and soda ash. Silica, or silicon dioxide, is the most important constituent in common commercial glasses. As it is the principal glass-forming oxide, silica or glass sand typically arrives at the glass plant by rail, is between 20 mesh and 100 mesh, contains between 99.6 and 99.8% SiO_2, and is very low in iron, i.e., less than 0.025%. Feldspar is used primarily as a source of alumina, but contributes some fluxing to the batch because of its soda and potash content. Feldspars, in general, are represented by the formula $R_2O \cdot Al_2O_3 \cdot 6SiO_2$ (where R_2O represents the alkali content). Dolomite and limestone are used as a source of calcia, the difference in the two being the much higher magnesia content in the dolomite. In addition to some fluxing, the purpose of the feldspar, dolomite, and limestone is to impart chemical durability to the glass, which is related to the RO-to-silica ratio and the alumina content. Soda ash is the primary fluxing agent in the batch. Fluxing, or lowering of the melting point, which imparts an improved workability to the glass, is accomplished by the Na_2O in the soda ash.

Prior to melting and feeding into the furnace, these raw materials - i.e., silica, feldspar, dolomite, limestone and soda ash--are carefully weighed and blended along with a number of other minor batch ingredients.

In a typical side port regenerative glass melting furnace (Figure IV-1), the box type regenerative checkers are on opposite ends, as are the burner ports, hence the term side port regenerative. In the end port regenerative glass melting furnace, the burner ports and checker structure are at one end. The checker structure is made up of a lattice of brickwork which allows the passage of air to support combustion. The checkers use waste heat to heat the incoming air for combustion, thereby providing higher flame temperatures and greater melting efficiency. An air-reversing valve channels the incoming air through one checker system and then the other.

Typically, the operation is as follows. Incoming air for combustion is heated as it passes through the hot checker system. This hot air meets the fuel in the burner port. The flame then burns over the surface of the glass within the space under the melter crown. The combustion gases leave the melting area through the opposite burner ports and through the other checker system, thereby heating these checkers. The furnace is operated in this mode for about 20 minutes before the flow is reversed through the other checker and port system. (Tooley, 1974)

Glass flow is perpendicular to the checkers and burners. The incoming glass-batch powders, which are a carefully premixed formulation of primarily silica, feldspar, dolomite, limestone, and soda ash, are fed across the melt at one end of the furnace. Due to the flow of the combustion gases over the glass powder as it is being melted, some particulate matter carries over to the checkers; to reduce carryover, it is critical to eliminate fine particles, i.e., those less than 100 mesh. To reduce dusting during mixing and feeding, the batch ingredients are wetted with about 2-3/4 gallons of water per ton of glass. The glass then moves through the melter from the feed, or dog-house, end to the finer.

The highest temperature in the melter is about 2920°F; at only slightly higher temperature, approximately 2950°F, the silica crown roof begins to soften and drip, thereby causing inhomogeneities which lead to rejects in the final glass product. Typical design specifications call for about 5 feet of melting area per ton of glass pulled per day. Hence, for a typical side port, regenerative furnace with a 200 tpd capacity, a melting area of about 1000 ft^2 would be required.

2. Energy Considerations

In general, the energy required to melt glass is influenced by batch composition, furnace size and design, and by the age of the furnace. For the melting of a soda-lime glass in a given side port regenerative furnace, the primary energy variable is furnace age. As a furnace ages, the spacing between checker bricks decreases because of carryover of unmelted particles from the raw batch by the combustion gases. These particles react and stick to the hot refractory brickwork. As aging continues, areas of the checkers eventually become plugged, or, due to the additional weight buildup, brickwork in the lower regions of the checkers collapse. The end result is a decrease in checker volume, hence a reduction of air preheating (Alexander, 1974), lowering of flame temperature and decrease in melting efficiency (Figure IV-2).

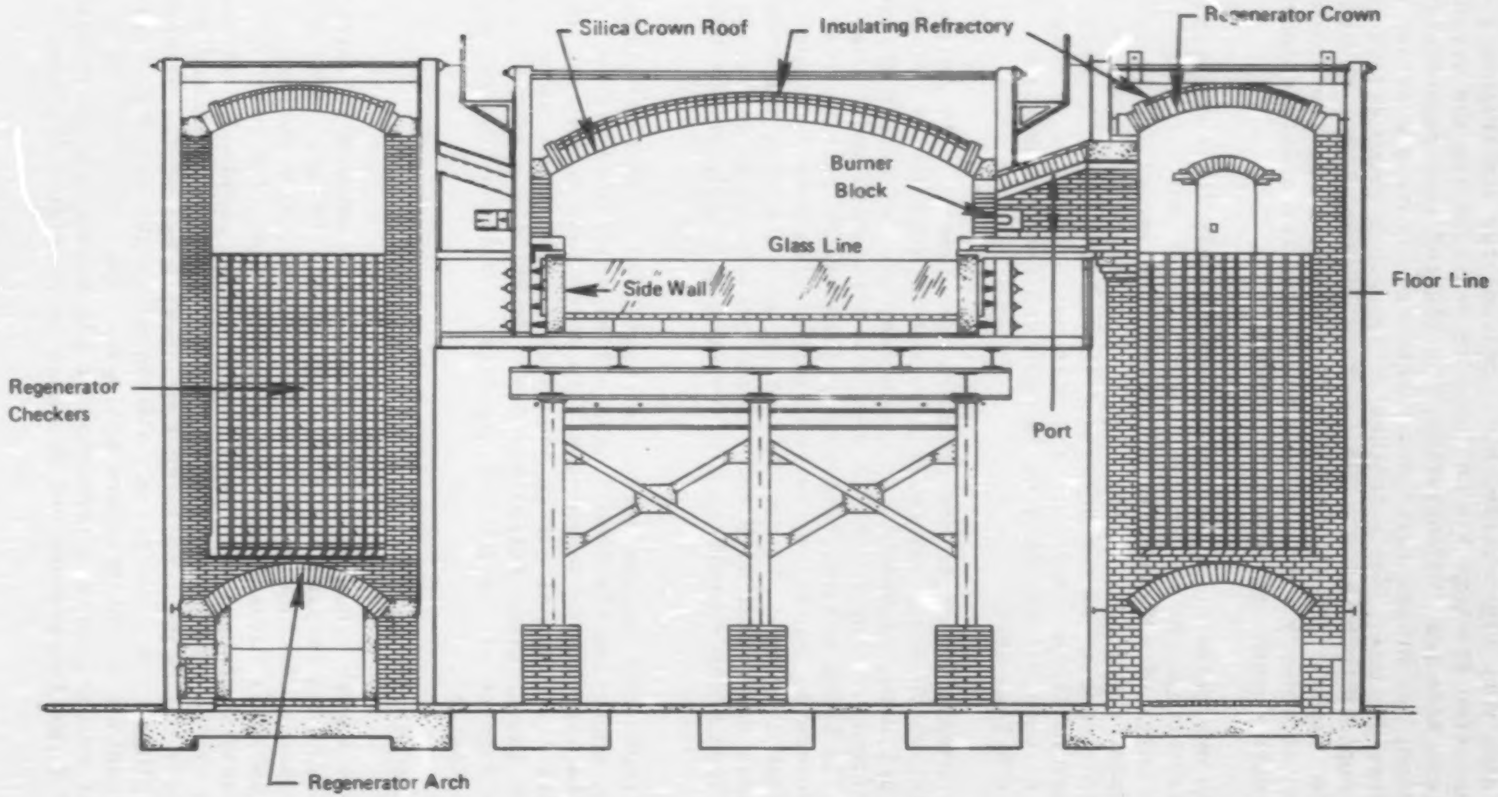

Silica Crown Roof
Insulating Refractory
Regenerator Crown
Burner Block
Glass Line
Side Wall
Floor Line
Regenerator Checkers
Port
Regenerator Arch

Figure IV-1. Typical Side Port Regenerative Furnace

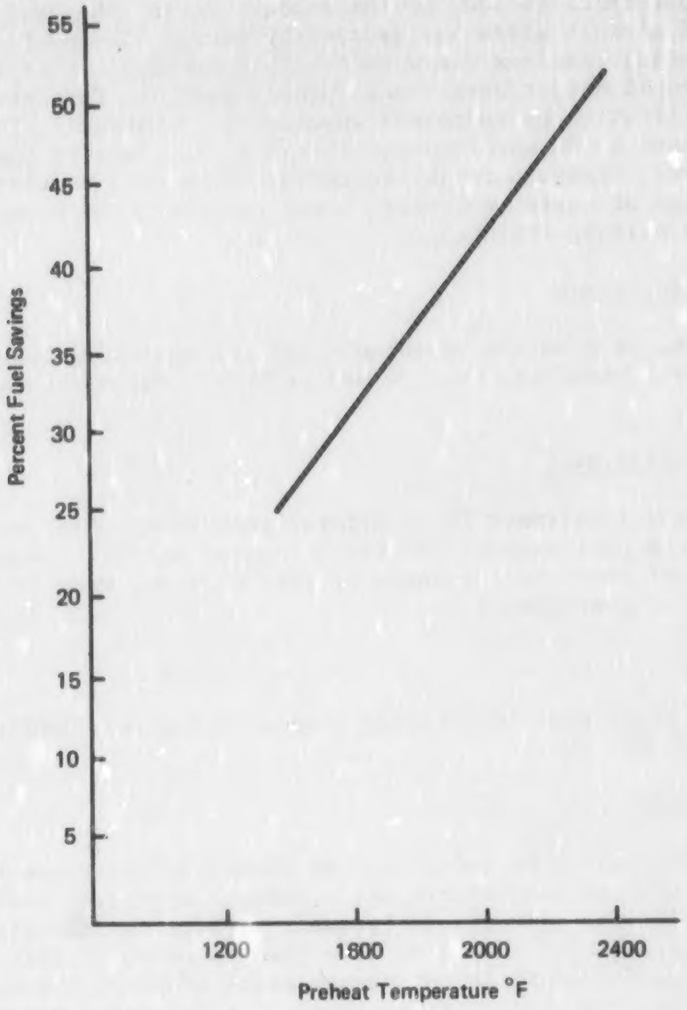


Figure IV-2. Fuel Savings Due to Regeneration

For an operation involving the melting of soda-lime in a gas-fired, side port, regenerative furnace, energy inputs vary from 5 to 9 x 10^6 Btu per ton of glass. For a 200 tpd operation, the typical energy required is about 6.8 x 10^6 Btu/ton. Approximately one-third of this energy is required to melt the raw materials entering the furnace, one-third is lost through the refractories, and one-third is lost up the stack. During the past 20 years the energy required to melt glass has dropped by nearly 50% (Hamilton, 1970). This considerable energy savings was made possible through better use of insulation, and through better burner and furnace design. Further improvements in energy utilization by increased insulation is minimal. The outside walls of the tank have to be water-cooled to extend the life of the furnace, consequently such heat losses through the refractories will remain high. Increased utilization of waste heat does however appear to be a reasonable approach to improve melting efficiency.

3. Economic Considerations

In this section, we give the investment and the operating costs for the melting process only; therefore, they do not reflect total manufacturing or investment costs.

a. Fixed Capital Investment

The fixed capital investment for a natural gas-fired, side port, regenerative furnace having a pull rate of 200 tpd is approximately $1.4 million. (The pollution control cost for a furnace of this type and size is covered in a latter part of this section.)

b. Production Cost

The total production cost for melting a soda-lime glass, including pretax ROI, is $72.67/ton (Table IV-2).

c. Raw Materials Cost

Costs of raw materials were calculated by obtaining delivered bulk materials costs for the various ingredients which make up a typical soda-lime glass batch and multiplying these costs by their required weight ratio (Table IV-3). The composition of a soda-lime glass does not differ significantly, hence raw material costs do not change significantly from one plant to another plant or for one process or another. The delivered raw material cost was estimated at $46.13 per ton of glass shipped.

d. Energy Costs

A 200 tpd glass furnace needs approximately 6.8 x 10^6 Btu to melt a ton of glass. Typically, this energy input varies between 5 and 9 Btu per ton of glass, depending upon furnace age, type, and size. The cost for natural gas was obtained by averaging the purchased price of this fuel in the East North Central region - which produces the majority of the glass manufactured

TABLE IV-2

PRODUCTION COST ESTIMATE: NATURAL GAS-FIRED, SIDE PORT, REGENERATIVE FURNACE - BASE CASE

Product: Soda-lime Container Glass

Daily Capacity: 200 tons

Annual Production: 65,700 tons

Location: East North Central

Fixed Investment: $1,404,600

	Units Used in Costing or Annual Cost Basis	$/Unit	Units Consumed per Ton of Product	Cost per Ton of Product ($)
VARIABLE COSTS				
Raw Materials & Shipping*				
• Sand	Net ton	20	0.758	15.16
• Feldspar	Net ton	34	0.072	2.45
• Dolomite	Net ton	63	0.132	8.32
• Limestone	Net ton	20	0.116	2.32
• Soda Ash	Net ton	68	0.263	17.88
Energy				
• Purchased Gas	10^6 Btu	2.06	6.8	14.00
• Electricity	kWh	0.0205	19.0	0.39
Water				
• Process	1000 gal	0.20	0.00275	0.00
• Cooling	1000 gal	0.03	0.275	0.01
Direct Operating Labor	Man-hour	5.03	0.19	0.96
Direct Supervisory Labor	Man-hour	7.29	0.02	0.15
Maintenance Labor				0.86
Maintenance Supplies				0.86
Labor Overhead				0.69
Miscellaneous Variable Costs				1.39
TOTAL VARIABLE COSTS				65.44
FIXED COSTS				
Plant Overhead				0.99
Local Taxes & Insurance				0.43
Depreciation - (@ 14 yr)				1.53
TOTAL FIXED COSTS				2.95
TOTAL PRODUCTION COST				68.39
RETURN ON INVESTMENT @ 20% PRETAX				4.28
TOTAL				72.67/ton

*See Table IV-3.

TABLE IV-3

BREAKDOWN OF RAW MATERIAL WEIGHTS AND COSTS

Basis of Calculation (%):			72.0	9.0	14.1	1.5	3.0	0.4	
Pounds	Raw Material	Cost/ Ton($)	SiO_2	CaO	Na_2O	Al_2O_3	MgO	K_2O	
678.9	Sand	20	675.5	-	-	3.4	-	-	
64.5	Feldspar	34	44.5	1.3	3.2	11.6	-	3.9	
118.0	Dolomite	63	-	36.6	-	-	24.8	-	
104.2	Limestone	20	-	52.1	-	-	5.2	-	
235.7	Soda Ash	68	-	-	137.9	-	-	-	
			720.0	90.0	141.1	15.0	30.0	3.9	(1000)

in the United States. In addition to the natural gas, some electrical energy is also required for instrumentation and controls. Typically, glass manufacturers consume about 1 x 10^6 Btu of electricity per ton of glass; of this, about 5-10% is estimated to be associated with melting (exclusive of electrical boosting).

e. Wages

Wage rates were determined by averaging production and nonproduction wages in this industry for the major mid-West glass producing states. The number of production employees for melting was taken as six, and the supervisory labor was taken as a fixed percentage, based upon the industry average, of the production labor.

f. Maintenance Labor and Supplies

Maintenance labor and supplies was taken as 6% of fixed capital investment.

g. Overhead

Plant and payroll overhead was taken as a fixed percentage of total labor. This includes maintenance labor which was taken as one-half of maintenance labor and supplies. A figure of 50% was used for plant overhead and a figure of 35% for payroll overhead.

h. Other Fixed Costs

Taxes and insurance were taken as 2% of the fixed capital investment of the glass melting furnace and depreciation was taken as 14 years straight line.

i. Miscellaneous Variable Cost

The miscellaneous variable cost figure, covering primarily the costs associated with the purchase and shipment of the minor batch ingredients (Table IV-4) was estimated at 3% of the raw materials cost. Many of the serious pollutants stem from these minor ingredients, such as sulfates. These ingredients have to be specific, and as such are quite critical to the batch. Primarily, they are used as fluxing agents, to lower melting temperature and to improve workability of the glass, or as fining agents to remove bubbles from the glass.

TABLE IV-4

TYPICAL COMMERCIAL GLASS BATCH MINOR ADDITIVES

Oxide	Material Source
Antimony Oxide	Stibnite
Arsenious Oxide	Arsenious Oxide
Barium Oxide	Barium Carbonate, Barium Sulfate
Boric Oxide	Borax, Boric Acid, Colemanite
Fluorine Oxide	Cryolite, Fluorospar
Phosphates	Bone Ash, Apatite
Lithia	Lithium Carbonate
Zinc Oxide	Zinc Oxide
Zirconia	Zircon

4. Environmental Considerations

a. Air Pollution

The air pollution emissions from a glass melting furnace include particulates, nitrogen oxides, sulfur oxides, and in some cases minor emissions of hazardous materials, such as fluorides, arsenic, lead, and a few others. (A detailed discussion of these emissions is contained in Source Assessment Document No. 3, Glass Manufacturing Plants, EPA Report No. 68-02-1320, November 1974, which we have relied upon heavily for most of the emission data reported here.)

Depending upon the glass composition and specific minor ingredients, the glass melting operation can result in the emission of particularly hazardous materials. The characteristics of the air pollutants, the control technology, and cost of control are all discussed in the following subsections.

(1) Characterization of Air Pollution Emissions

A glass melting furnace has both particulate and gaseous emissions which must be controlled (Table IV-5).

The major gaseous pollutant is nitrogen oxide, which is formed during the combustion of natural gas. Because of the high temperatures required for the furnace, the gas combustor must be operated at temperatures favorable to nitrogen oxide formation.

The sulfur oxide emissions arise from two sources: sulfur in the fuel and decomposition of mineral sulfates in the glass melt. The sulfur within the fuel is usually a minor source of sulfur oxide emissions and generally results in the production of SO_2. The decomposition of mineral sulfates in the melt produces sulfur in the form of SO_3, which is much more corrosive than SO_2. Although some of the SO_3 decomposes to SO_2 at temperatures above 2790°F, some will remain in the form of SO_3. If the furnace gases are cooled to below the acid dew point (about 230°F), the SO_3 will condense with water vapor to form sulfuric acid mist, which is corrosive and a serious health hazard.

Two classes of particulates should be considered: those entrained by the hot combustion gases and those formed by the volatilization of materials in the glass melt. The latter are by far the more hazardous because they are submicronic and are in the form of sulfate salts with trace quantities of fluorides, lead, arsenic, boron, or other heavy metals, depending upon the type of glass that is produced. For example, opal glass generates a considerably greater amount of fluorides than soda-lime glass; lead emissions are found primarily in lead glass; and arsenic and selenium are common constituents in some tinted glass.

In addition, there are emissions of carbon monoxide and hydrocarbons, both of which are believed to be the result of incomplete fuel combustion or decomposition of powdered coal in the batch which is sometimes added to reduce sulfate to sulfite in the melt. These emissions, considered to have a minor impact, are easily controlled.

TABLE IV-5

GLASS MELTING FURNACE EMISSIONS

Species	Emission Rate lb/ton of Glass Produced	(kg/ton)
NO_x	8	4
SO_x	3	1.5
Particulates	2	1
CO	1	0.5
Hydrocarbons	0.2	0.1
Arsenic	0.6	0.3
Selenium	0.03	0.015
Antimony	0.1	0.05
Cl_2 or HCl	0.1	0.05
Fluorides (opal glass)*	22	11
Fluorides (soda-lime glass)	0.1	0.05
Lead	10	5
Borates	20	10

Source: Assessment Document No. 3, Glass Manufacturing Plants, EPA Report No. 68-02-1320, November 1974.

(2) Control Technology

(a) Gaseous Emissions - The only viable control technique for nitrogen oxide at the present time is maintaining the proper combustion conditions in the furnace. For example, low excess air firing and no air preheating both produce minimum nitrogen oxide emissions. As is the case with utility boilers, the control of nitrogen oxides is based upon modification of combustion conditions, and the costs of control are included as a part of the furnace manufacturing costs.

The sulfur oxide emissions are expected to have an abnormally high concentration of SO_3 as opposed to SO_2 in the stack gas. This is expected to increase the corrosion potential of the stack gas and make air pollution control more difficult, more costly, and more necessary. The control techniques for SO_2 and SO_3 consist of contacting the gases with caustic or lime to convert the gaseous emissions to sulfate or sulfite salts of sodium and calcium. Scrubbers for this purpose should utilize high efficiency entrainment separators to avoid carryover of sulfuric acid mist to other control devices into the stack.

(b) Particulates - The particulates present the most difficult of the control problems encountered in the glass melting furnace. In the submicron particle range typical of glass furnace emissions (Figure IV-3), the collection efficiency of most air pollution control devices falls off drastically (Figure IV-4).

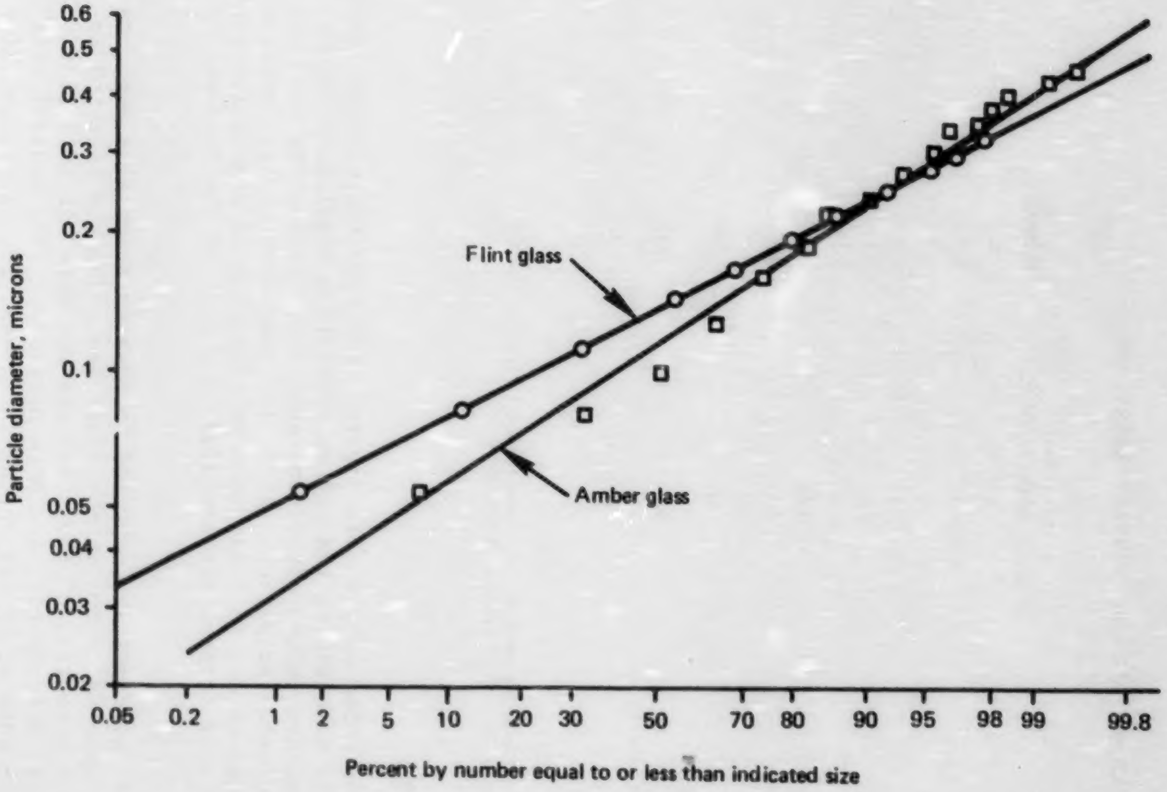
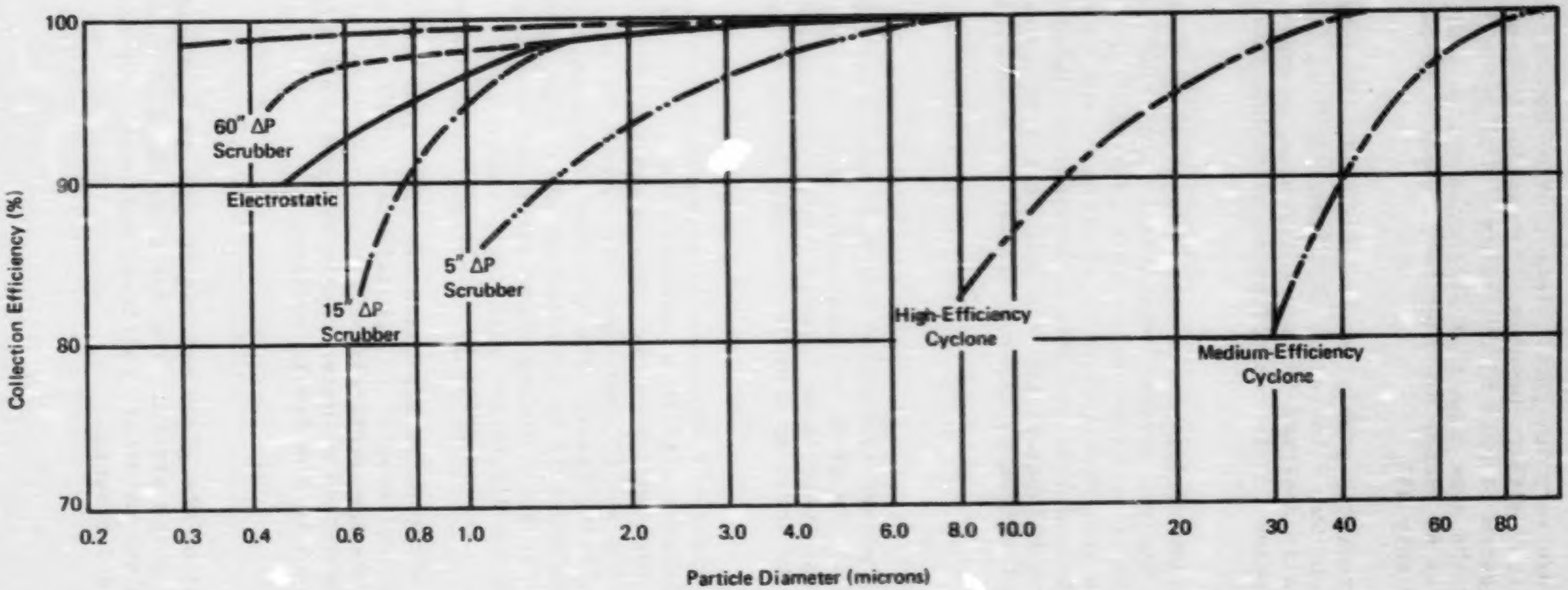


Figure IV-3. Log-Probability Distribution of Particle Sizes Present in Glass Furnace Effluent



Source: Arthur D. Little, Inc.

Figure IV-4. Performance Comparison for Particulate Control Systems

At present, there are very few particulate control devices that have been demonstrated on glass melting furnaces. The use of high-efficiency wet scrubbers has been suggested because of the advantage of being able to treat the acid stack gases at the same time that particulates are removed. However, pressure drops as high as 65 inches of water have resulted in particle collection efficiencies of only 95%.

Conventional electrostatic precipitators have collection efficiency limits similar to those of wet scrubbers. NAFCO Engineering, Ltd., using a precipitator specifically designed for glass furnaces in Japan, has obtained slightly higher efficiencies. This technology is available in the United States as well.

The highest collection efficiency is generally attained using fabric filters. In the United States, several demonstrations carried out with different types of bags have shown efficiencies in excess of 99%. On the other hand, fabric filters are very susceptible to blinding by the condensation of vapors within the fabric. This has been a particularly bothersome problem in the glass industry because of the acid mist carryover, suggesting that for the system to work effectively, careful regulation of gas temperatures will be required.

(3) Cost of Control

Because of a lack of proven technology for both the gaseous and particulate emissions very few of the glass melting furnaces in the United States are controlled. Therefore, there is no "typical" air pollution control system readily available to serve as a basis for calculation of typical costs of control.

In the absence of a clear-cut consensus on appropriate control technology, we have assumed what we believe will be an adequate control system (Figure IV-5) and have based our cost estimates upon this assumption (Table IV-6). In this type of control, SO_2 and SO_3 emissions are removed by a spray scrubber with soda ash as a neutralizing agent. The scrubber is not intended as a particulate control device and will be operated at low energy. However, many of the large particulates, including those entrained by the combustion gases, will settle out and be discharged with the scrubber purge. The purged wastewater must be further treated prior to discharge from the plant.

The gases leave the scrubber at approximately 120°F (the dew point of the combustion gases) and are reheated to approximately 250°F prior to entering the fabric filter, where the particulates are removed. The reheat is necessary to prevent condensation of water vapors or acid mists within the fabric filter which would blind the fabric surface.

b. Water Pollution

The wet scrubber used on the glass melting furnace is operated in a recycle mode with a small purge stream. The purge stream will contain high concentrations of particulate material, sulfites, sulfates, and trace metals, such as selenium, boron, and arsenic.

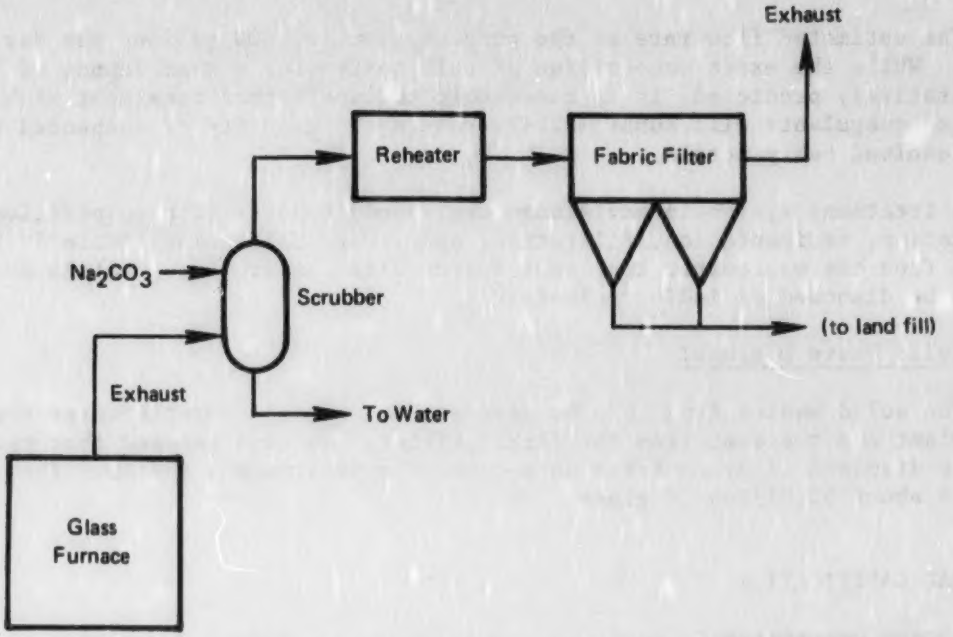


Figure IV-5. Air Pollution Control System for Glass Melting Furnace

TABLE IV-6

AIR POLLUTION CONTROL COSTS
(Basis: 200 tpd of glass)

CAPITAL COSTS ($)	
Spray Scrubber System	434,200
Reheater	49,700
Fabric Filter	389,800
Total Direct Costs	873,700
Indirects @30% of Direct Costs	262,100
TOTAL CAPITAL COST	1,135,800
ANNUAL OPERATING COSTS ($/yr)	
Direct Costs	
Labor (plus Supervision and Overhead), 1/2 man/shift @$9.25/hr (total)	40,500
Maintenance @5% of Capital	56,800
Utilities	
-Electric Power, 1.54 x 10^6 kWh/yr @$0.0205	31,600
-Fuel, 23.31 x 10^9 Btu/yr @$2.06/$10^6$ Btu	48,000
-Water, 19.5 x 10^6 gal/yr @$0.20/1000 gal	3,900
Chemicals, 106 tons (Na_2O)/yr @$56/ton	5,900
Total Direct Costs	186,700
Indirect Cost	
-Depreciation, 14 years	81,100
-Insurance and Taxes @2% of Capital	22,700
Total Indirect Costs	103,800
Return on Investment @20% of Capital	227,200
TOTAL ANNUAL COST ($/yr)	517,700
Unit Cost ($/ton of glass)	7.09

Source: Arthur D. Little, Inc., estimates.

The estimated flow rate at the purge system is 7200 gallons per day (gpd). While the exact composition of this wastewater stream cannot be quantitatively predicted, it is reasonable to expect that treatment with lime and coagulants will substantially reduce the quantity of suspended solids and dissolved heavy metals.

A treatment system is envisioned that would consist of precipitation/coagulation, sedimentation, filtration, and sludge thickening (Table IV-7). Sludge from the wastewater treatment system will contain heavy metals and cannot be disposed of indiscriminately.

c. Solid Waste Disposal

The solid wastes from this process are the sludge from the water treatment plant and the dust from the fabric filter. We have assumed that these will be disposed of by contract at a cost of approximately $5/ton. The total cost is about $0.01/ton of glass.

C. COAL GASIFICATION

1. Process Description

Generally, coal gasification processes include, in some variation, the following steps:

- coal handling and storage
- coal preparation
- gasification
- oxidant feed facilities
- gas cleaning

The variations depend on the peculiarities of each type of gasifier and the type of fuel used. A coal gasification system suitable for a glass manufacturing operation is either a single-stage gasifier (Wellman-Galusha) or a two-stage gasifier.

Coal of any rank with a low swelling index can be gasified in the Wellman producer. The coal must be sized to the range of about 3/8" to 2-1/2". Undersize can cause bridging whereas oversize may reduce mass transfer rates and affect gas distribution.

Predrying of the coal is only necessary to the extent that surface moisture may cause fines to cling to the larger coal particles during screening. In an oxygen-blown system, the total moisture may affect economics to the extent that more coal must be burned in the gasifier to vaporize the moisture. Depending on the coal, therefore, a drier may be warranted.

TABLE IV-7

WASTEWATER TREATMENT COST: GLASS MELTING VIA NATURAL GAS-FIRED FURNACE - BASE CASE

(Basis: 200 tpd - 365 days/year Production)

CAPITAL INVESTMENT		$95,000
Operating Cost		
Direct Operating Costs		
Labor (plus supervision & overhead)	$10,200	
Maintenance	3,800	
Chemicals	500	
Electricity	1,400	
Sludge Disposal	3,200	
Total Direct Operating Costs		$19,100
Indirect Costs		
Depreciation, 14 years	$ 6,800	
Taxes and Insurance (@2%)	1,000	
Total Indirect Cost		$ 8,700
Return on Investment (@20%)		$19,000
TOTAL ANNUAL COST		$46,800
Unit Cost ($/ton of glass)		0.64

NOTES:

1) Treatment consists of:
   - precipitation/coagulation
   - sedimentation
   - multi-media filtration
   - sludge thickening
2) Capital investment adjusted to March 1975 (ENR=2126)
3) Quantities:
   a) labor - 1050 man-hours/yr @ $9.75/man-hour (including supervision, labor overhead, and plant overhead)
   b) chemicals - 2.2 tpy hydrated lime @ $100/ton; 1.1 tpy sulfuric acid @ $100/ton; 40 lb/yr coagulant @ $1.00/lb

   Electricity - 65,400 kWh/yr @ $0.0089/kWh

   Sludge - 630 tpy (wet basis) @ $5.00/ton

The Wellman-Galusha concept (Nelson, Applied Technology)(Figure IV-6) is a single-stage, fixed-bed gasifier which operates at atmospheric pressure using oxygen, or air, and steam. Coal is fed through a rotating drum feeder to the top of the bed, and slowly falls through the vessel as the coal is gasified and ash is removed through the eccentrically rotating grate at the bottom. Oxidant and steam are injected at the bottom to initiate the gasification and combustion reactions. These hot, gaseous products rise through the bed, heating and devolatilizing the coal before leaving at about 1000°F at the top of the gasifier.

The vessel is constructed of water-jacketed, unlined steel. The steam generated in the jacket is more than sufficient for process purposes (about 10-15% excess).

Except when operated on anthracite, the Wellman-Galusha gas contains considerable tars which condense in distribution headers in large quantities. Generally, the plant must be shut down every two weeks or so to burn out the deposits in the headers and distribution lines, an expensive and unsafe operation.

To avoid the tar problem, a two-stage version of the gasifier has been developed to allow for removal of two separate gas streams from the gasifier, one a tar-rich and the other a tar-free gas. The former may then be treated for tar droplet removal via cyclone. Before distribution to the users, the cool gas, now containing only a small quantity of tar droplets, is mixed with the hot gas stream (after dust collection) to vaporize any remaining tar. The product gas is referred to as a hot raw gas.

Alternatively the gas may be further processed to produce a cold, clean gas. For virtually complete tar removal, the tar-rich gas is treated as above with the addition of an electrostatic precipitator. Meanwhile, the hotter, bottom gas is cooled in a spray column. The gases are then mixed upon entry into a cooler, after which any condensed light oils may be separated and recovered.

2. Energy Considerations

For purposes of comparison it was assumed that the same energy input is required to melt glass with a low-Btu bituminous producer gas as it is with natural gas, namely 6.8 x 10^6 Btu per ton of glass. Furthermore, a coal with a fixed heating value, sulfur, and moisture content was used for this coal-fired process as well as for the other two which will be discussed later. These values were fixed as follows:

Heating value (Btu/lb coal)	11,100
Sulfur content (%)	3.2
Moisture content (%)	12.5
Ash (%)	9.6

From this, it was calculated that

$$\frac{6.8 \times 10^6 \text{ Btu}}{\text{ton}} \cdot \frac{\text{Pound of Coal}}{11{,}100 \text{ Btu}} \cdot \frac{\text{ton}}{2000 \text{ lb}}$$

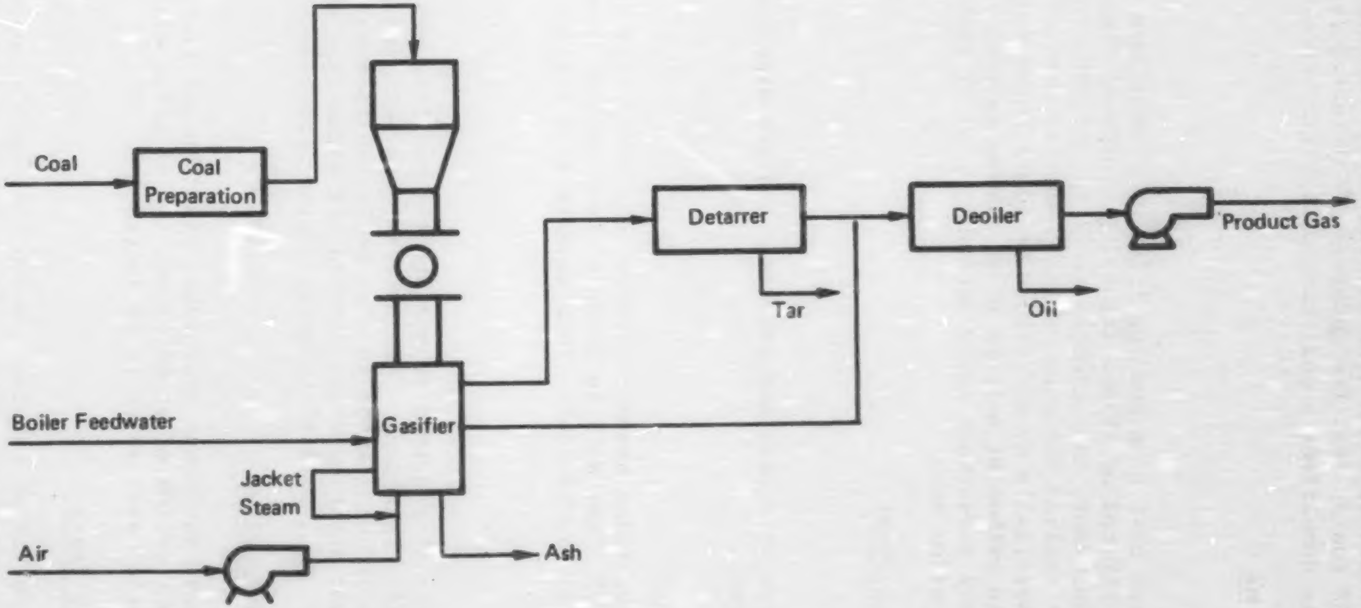

Coal
Coal Preparation
Boiler Feedwater
Jacket Steam
Air
Gasifier
Ash
Detarrer
Tar
Deoiler
Oil
Product Gas

Figure IV-6. Wellman Two-Stage Gas Process

or 0.31 ton of coal is required to melt one ton of glass. However, the efficiency of the gasifier must be taken into account, and, assuming an 80% conversion efficiency, 0.38 ton of coal (Arrandale, 1974a) is required per ton of coal. Also, in this comparison a coal cost of $20 per ton was assumed.

3. Economic Considerations

a. Capital Investment

The incremental capital cost of a coal gasifier capable of producing sufficient energy to melt 200 tpd of glass, including equipment installation but excluding pollution equipment, is estimated to be $1,380,000. Furthermore, this capital cost does not include the glass melting furnace cost; the assumption has been made that essentially no difference in glass furnace cost will be incurred when using this method of melting glass versus melting with natural gas firing. This additional investment is reflected by a $1.91 increase in the fixed portion of production cost.

b. Production Cost (Table IV-8)

(1) Raw Materials

Raw materials costs for this case and the base case are expected to remain essentially unchanged.

(2) Energy

On the basis of our operating assumptions, we have calculated that an decrease of $6.79 per ton of glass will be incurred by a switch in energy generation form from natural gas to coal. This amounts to a fuel-energy savings of about 55%.

(3) Labor

Additional direct labor is required to operate the gasifier and an increase of $3.87 per ton is estimated. This amounts to a 400% increase in direct labor cost. This additional labor is also reflected in supervisory labor, payroll overhead, and plant overhead. It is estimated that the total increase will be $10.27 per ton, or 368% relative to the base case.

(4) Maintenance Labor and Supplies

Because of the increased equipment associated with the gasifier, an increase in maintenance cost estimated at $4.43 per ton of glass will be incurred relative to the base case, which is an increase of 257%.

(5) Miscellaneous Variable Costs

It is estimated that operating supplies, which make up the major portion of this category, will also increase. This increase has been estimated at $4.67 per ton of glass shipped, which is an increase of 336%.

TABLE IV-8

PRODUCTION COST ESTIMATE: COAL GASIFICATION

Product: Soda-lime Container Glass

Daily Capacity: 200 tons

Annual Production: 65,700 tons

Location: East North Central

Fixed Investment: $1,[illegible]0,000 + $1,404,600 for glass melting furnance

	Units Used in Costing or Annual Cost Basis	$/Unit	Units Consumed per Ton of Product	Cost per Ton of Product ($)
VARIABLE COST				
Raw Materials & Shipping				
• Sand	Net ton	20	0.758	15.16
• Feldspar	Net ton	34	0.072	2.45
• Dolomite	Net ton	63	0.132	8.32
• Limestone	Net ton	20	0.116	2.32
• Soda Ash	Net ton	68	0.263	17.88
Energy				
• Purchased Coal	Net ton	20	0.38	7.60
• Electricity	kWh	0.0205	19.0	0.39
Water				
• Process	1000 gal	0.20	0.00275	0.00
• Cooling	1000 gal	0.03	0.275	0.01
Direct Operating Labor	Man-hour	5.03	0.96	4.83
Direct Supervisory Labor	Man-hour	7.29	0.11	0.82
Maintenance Labor				3.08
Maintenance Supplies				3.08
Labor Overhead				3.05
Miscellaneous Variable Cost				6.05
TOTAL VARIABLE COST				5.04
FIXED COST				
Plant Overhead				4.36
Local Taxes & Insurance				0.85
Depreciation				3.02
TOTAL FIXED COST				8.23
TOTAL PRODUCTION COST				83.27
RETURN ON INVESTMENT				8.47
TOTAL				91.74/ton

4. Environmental Considerations

a. Air Pollution

When coal gasification is used to generate a gaseous fuel for the glass melting furnace, the major environmental difference is not in the glassmaking process, but rather in the fuel generating process for the furnace. The implications of this on the fuel-generation process and the glass-melting process are discussed in the following subsections.

(1) Fuel Generation

The fuel gas produced in the coal gasifier will contain sulfur, mainly in the form of H_2S. So that excessive SO_2 emissions do not occur, the sulfur must be controlled either before or after gas combustion in the furnace. Two control technologies could be considered: a sulfur-recovery process, such as the Stretford process, to remove H_2S from the fuel gas prior to burning the fuel in the furnace, or flue gas desulfurization, such as the processes currently used on utility boilers for removing SO_2 from exhaust gases. The latter case is the same as the control for direct coal firing (which is discussed elsewhere in this report). As previously noted, a large increase in the sulfur loading of the exhaust would greatly increase the problem of air pollution control for the glass furnace, and the fluctuation in control costs could be considerable. We have, therefore, included for comparison the alternative of removing sulfur as H_2S prior to firing the fuel into the glass furnace. The Stretford process is an example of appropriate sulfur recovery technology for this application. The capital cost for a Stretford plant was estimated for a 200 tpd glass melting furnace, based on the sulfur recovery rate of 2.2 long tons per day (Table IV-9).

(2) Glass Furnace Controls

Once the H_2S has been removed, the only difference between the base case and the heating of a glass furnace using fuel gas from a coal gasifier is that the exhaust gases for the coal gasifier case will be slightly greater in volume than those of the base case (Table IV-10). There is about a 10% difference in the gas flows between the coal gasification case and the base case. As a consequence, the air pollution control system for the furnace using fuel gas will be correspondingly larger in size, and the costs of control will reflect this difference. The air pollution control costs (Table IV-11), based upon the utility requirements (Table IV-12), and the energy consumption for the coal gasification case are only slightly greater than the corresponding costs and utility requirements for the base case.

b. Water Pollution

The coal gasification alternative will produce two wastewater streams, a wet scrubber stream (of essentially the same size and composition as that described under the base case), and a small wastewater stream from the Stretford unit. In addition there will be the usual coal storage run-off wastewaters that may have to be treated.

TABLE IV-9

SULFUR CONTROL COSTS FOR COAL GASIFIER
(Basis: 2.2 long ton/day Sulfur Recovered via Stretford Process)

Annual Operating Cost ($/yr)	
Direct Operating Costs	
Labor (plus supervision & overhead), 1/3 man/shift @ $9.25/hr (total)	27,000
Maintenance @ 5% of Capital	53,300
Utilities	
- Electric Power, 2000 kWh/long ton @ $0.0205/kWh	32,900
- Fuel (3.8 x 10^6 Btu/long ton @ $\$2.06/10^6$ Btu	6,300
- Cooling Water (250,000 gal/long ton @ $0.03/ 1000 gal	6,000
Chemicals @ $2.50/long ton	2,000
Total Direct Costs ($/yr)	127,500
Indirect Costs ($/yr)	
Depreciation	76,100
Local Taxes & Insurance @ 2% Capital Investment	21,300
Total Manufacturing Cost	97,400
Return on Investment @ 20% of Capital Investment	213,000
TOTAL ANNUAL POLLUTION CONTROL	438,100
Unit Cost ($/ton of glass)	6.00

TABLE IV-10

STACK GAS FLOW RATES
(Basis: 200 tpd of glass)

Location	Natural Gas	Direct Coal	Coal Gasification	COHOGG	Electric	Particle Agglomeration
Exit of Furnace Combustion Gases (scfm)	10,900	12,500[2]	12,300[3]	15,600[4]	--	8,800[5]
Melt-off Gases (scfm)	400	400	400	400	400	400
Total (scfm)	11,300	12,900	12,700	16,000	400	9,200
Exit from Scrubber						
- added water vapor[6] (scfm)	5,630	6,430	6,330	7,970	150	1,860
Total (scfm)	16,930	19,330	19,030	23,970	650	11,060
Exit from Reheater						
- added burner exhaust[7]	570	660	650	810	20	370
Total (scfm)	17,500	19,990	19,680	24,780	670	11,430
Stack Exhaust @ 250°F	23,440	26,660	26,370	33,200	900	15,310

[1] 6.8×10^6 Btu - Higher heating value (hhv)/ton @ 10% excess air; 6.1×10^6 Btu - Lower heating value (lhv)/ton

[2] 6.4×10^6 Btu (hhv)/ton @ 35% excess air; 6.1×10^6 Btu (lhv)/ton

[3] 6.6×10^6 Btu (hhv)/ton @ 10% excess air; 6.1×10^6 Btu (lhv)/ton

[4] 8.0×10^6 Btu (hhv)/ton @ 35% excess air and 80% efficiency; 6.1×10^6 Btu (lhv)/ton at furnace

[5] 5.5×10^6 Btu (hhv)/ton @ 10% excess air;

[6] Required to cool gas from 1300°F exhaust temp. to 120°F

[7] Exhaust temp. is 800°F

[8] Exhaust temp. is 600°F

[9] Required to heat to 250°F

TABLE IV-11

AIR POLLUTION CONTROL COSTS FOR GLASS MELTING FURNACE
(Basis: 200 tpd of glass)

Heat Source	Natural Gas	Direct Coal	Coal Gasification	COHOGG	Electric	Particle Agglomeration
Total Capital Cost ($000)	1,136	1,420	1,231	1,430	304	950
Annual Operating Cost ($000/yr)						
Direct Costs						
Labor (plus supervision & overhead) @ $9.25/hr	40	40	40	40	40	41
Maintenance @ 5% of capital	57	71	62	72	15	
Utilities						
- Electric Power @ $0.0205/kWh	32	37	35	44	2	21
- Fuel @ $2.06/$10^6$ Btu	48	56	55	68	2	31
- Water @ $0.20/1000 gal	4	5	4	5	1	2
Chemicals @ $56/ton Na_2O, $25/ton lime	6	55	6	6	6	6
Total Direct Costs ($000/yr)	187	256	202	235	66	101
Indirect Costs						
Depreciation, 14 years	81	101	88	102	22	68
Return on Invest. @ 20% of Cap.	227	284	246	286	61	190
Ins. & Taxes @ 2% of Cap.	23	28	25	29	6	19
Total	331	413	359	417	89	277
TOTAL ANNUAL COST ($000/yr)	518	667	561	652	155	378
Unit Cost, $/ton of Glass	7.09	9.14	7.68	8.93	2.12	5.18

TABLE IV-12

UTILITY REQUIREMENTS FOR AIR POLLUTION CONTROL
(Basis: 200 tpd of glass)

Item	Natural Gas	Direct Coal	Coal Gasification	COHOGG	Electric	Particle Agglomeration
Electric Power (10^6 kWh/yr)						
- air pollution	1.56	1.80	1.70	2.18	0.97	1.02
- water pollution	0.07	0.21	0.07	0.07	0.07	0.07
Total Electric Power	1.63	2.01	1.77	2.25	1.04	1.09
Total Fuel (10^6 Btu/yr) (air pollution only)	23310	26990	26500	33130	820	15130
Total Water (10^6 gal/yr) (air pollution only)	19.5	24.5	22.0 (1)	26.5	3.1	8.2

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(1) Includes scrubber purge, evaporation losses, and also Stretford purge for local gasification alternative.

It is estimated that the wastewater stream from the Stretford unit will have a flow rate of approximately 1000 gpd and will have the following composition:

Constituent	Concentration mg/l	Waste Load lb/day
Sodium carbonate	4700	39.2
Sodium Anthraquinone disulfonate	700	5.8
Sodium meta-vanadate	300	2.5
Sodium citrate	300	2.5
Sodium thiosulfate	6000	50.0
Sodium thiocyanate	6000	50.0

Although some of the waste constituents (such as sodium citrate) are biodegradable, others are only marginally so. Conceivably, biological treatment could be employed, but it is impossible to even speculate on its effectiveness. Because of this uncertainty and the very small volume of the waste stream, it is believed that contract disposal would be a more feasible, dependable alternative to evaluate. In contract disposal, the liquid waste would be hauled away by tank truck and treated and disposed of in the contractor's own treatment facility.

Contract disposal fees are generally on the order of $0.50 per gallon. The total annual cost for contract disposal of the Stretford wastewater stream would be $182,500, or $2.50 per ton of glass.

The treatment of the scrubber purge is the same as the treatment described for the scrubber purge in the base case. The estimated cost is about $0.64 per ton of glass (Table IV-13).

Therefore, the total wastewater treating cost for this alternative is:

Waste Stream	Cost ($/Ton of Glass)
Furnace scrubber water treating	0.64
Stretford purge (by contract @ $0.50/gal)	2.50
Total	3.14

c. Solid Waste Disposal

The coal ash can contain a wide variety of substances, such as metal compounds; consequently, its disposal into landfills or redeposition into coal mines should be carried out in a manner which will, under any possible conditions, prevent pollution of ground water by leaching.

For the example case, we have assumed a coal ash content of 9.6%, in which case the coal gasifier will generate approximately 2700 tons of ash per year. This can be disposed of at a rate of $5.00 per ton, for a total cost of approximately $13,500, or approximately $0.21 per ton of glass.

The dust from the fabric filter amounts to only 73 tons per year and can be landfilled with the coal ash at a cost of only $0.01 per ton of glass.

TABLE IV-13

WATER POLLUTION CONTROL COSTS FOR GLASS MELTING FURNACE
(Basis: 200 tpd of glass)

Heat Source	Natural Gas (Base Case)	Direct Coal	All Others (Same as Base Case)
Total Capital Cost ($000)	95	192	95
Direct Operating Costs ($/yr)			
Labor (plus supervision & overhead) @ $9.25/hr	10,200	10,200	10,200
Maintenance @ 4% of Capital	3,800	7,700	3,800
Chemicals	500	1,600	500
Electric Power @ $0.0205/kWh	1,400	1,400	1,400
Sludge Disposal	3,200	20,600	3,200
Total	19,100	44,500	19,100
Indirect Costs			
Depreciation, 14 years	6,800	13,700	6,800
Insurance & Taxes @ 20% of Capital	1,900	3,800	1,900
Total Water Pollution Control Costs	8,700	17,500	8,700
Return on Investment @ 20% of Capital	19,000	38,400	19,000
TOTAL ANNUAL COST ($/yr)	46,800	100,400	46,800
Unit Cost ($/ton of Glass)	0.64	1.38	0.64

The sulfur removed by the Streford process amounts to only 912 tons per year. In our opinion, this is not enough to warrant any attempt to market sulfur as a byproduct. Therefore, this solid waste will be landfilled along with the others. The cost is less than $5000 per year, or about $0.06 per ton of glass.

D. DIRECT COAL FIRING

Pulverized coal flames have been used to provide energy in cement processing and in some metallurigical processing but essentially never have been used in glass processing. One exception, however, has been reported and that was by Coors, in Colorado, in which they replaced several of their gas burners in one furnace with coal burners. Also, Columbine Glass (Miller and Fogelberg, 1975) has sponsored research concerning coal utilization. In this study one of the natural gas burners was replaced by a pulverized coal burner at a location near the bridge wall of the furnace, and was used to supply about one-twentieth of the total energy requirement of the furnace. The duration of the trial test was four days.

1. Process Description

To use coal directly in burners a coal storage area is needed as well as a live coal storage bin, a pulverizer, screens, a feeder, and the pulverized coal burner(s). A coal storage area capable of storing about one month's supply appears reasonable. Some means of conveying the lump coal from this storage area to the pulverizer must be provided. The pulverizer is used to crush the coal to about 200 mesh screens then would be used to remove large coal particles, i.e., greater than about 0.02 inch (28 mesh). A separate conveying system is used to convey the powdered coal to a coal hopper or live storage bin. From this bin powdered coal is metered and fed to the burner along with the primary air supply. In the burner a secondary air supply is also introduced and the coal is burned.

2. Energy Considerations

Direct coal firing has the advantage over the other coal-firing processes in that it uses all of the heating value of the coal. The other, i.e., indirect methods, have about an 80% utilization factor, based upon consumption of 0.37 ton of coal per ton of glass (Arrandale, 1974a), hence direct coal firing offers considerable energy savings.

To compare direct coal firing with other forms of energy to melt glass, we assume that it is technically feasible to convert all of the natural gas burners in the furnace to direct-coal-fired burners. Also, we assume that it will require 6.8×10^6 Btu to melt a ton of glass. Therefore, as noted earlier, for a coal having a heating value of 11,100 Btu per pound, the daily coal requirement to the burner will be

$$\frac{6.8 \times 10^6 \text{ Btu/ton}}{11,100 \text{ Btu/lb}} \times \frac{1}{2000 \text{ lb/ton}} \times \frac{200 \text{ tons}}{\text{day}} = 62 \text{ tons of coal/day}$$

3. Economic Considerations

a. Capital Investment

For the direct-coal-fired process, the incremental capital costs are estimated to be $355,000, or 25% more than the base case. This increased investment, which also affects taxes and insurance, will have an overall effect of increasing the melting cost by $0.49 per ton.

b. Production Costs (Table IV-14)

(1) Raw Materials

The raw materials costs for this process will remain essentially the same as for the base case.

(2) Energy

On the basis of our operating assumptions, we estimate a decrease in fuel cost of $7.41 per ton for direct coal firing relative to natural gas firing.

(3) Labor

We estimate that an incremental increase in labor and labor-associated costs will be incurred relative to the base case. This increase, estimated to be $0.41 per ton, or 15%, results from the need to handle large volumes of coal.

(4) Maintenance Labor and Supplies

We estimate that an increase in maintenance cost of $0.32 per ton, or 19%, will be incurred.

(5) Miscellaneous Variable Costs

We estimate that this cost will remain essentially unchanged from the base case.

Overall, we estimate that direct coal firing will decrease glass melting cost by $5.50 per ton of glass, or about 7.5% from the base case. Based upon a selling price of $185 per ton, this decrease in melting cost of $5.50 per ton reflects an overall decrease of nearly 3%.

4. Environmental Considerations

a. Air Pollution

The major difference between the base case and direct coal firing is that coal is a slightly more difficult fuel to burn and will require a greater amount of excess air to achieve proper combustion. In addition, coal

TABLE IV-14

PRODUCTION COST ESTIMATE: DIRECT COAL FIRING

Location: East North Central

Product: Soda-lime Container Glass

Fixed Investment: $1,760,000

Daily Capacity: 200 tons

Annual Production: 65,700 tons

	Units Used in Costing or Annual Cost Basis	$/Unit	Units Consumed per Ton of Product	Cost per Ton of Product ($)
VARIABLE COST				
Raw Materials & Shipping				
• Sand	Net ton	20	0.758	15.16
• Feldspar	Net ton	34	0.072	2.45
• Dolomite	Net ton	63	0.132	8.32
• Limestone	Net ton	20	0.116	2.32
• Soda Ash	Net ton	68	0.263	17.88
Energy				
• Coal	Net ton	20	0.31	6.20
• Electricity	kwh	0.0205	19.0	0.39
Water				
• Process	1000 gal	0.20	0.00275	0.00
• Cooling	1000 gal	0.03	0.275	0.01
Direct Operating Labor	Man-hour	5.03	0.22	1.11
Direct Supervisory Labor	Man-hour	7.29	0.02	1.15
Maintenance Labor	--			1.02
Maintenance Supplies	--			1.02
Labor Overhead	--			0.80
Miscellaneous Variable Cost	--			1.39
TOTAL VARIABLE COST				58.22
FIXED COST				
Plant Overhead				1.14
Local Taxes & Insurance				0.54
Depreciation				1.91
TOTAL FIXED COST				3.59
TOTAL PRODUCTION COST				61.81
RETURN ON INVESTMENT				5.36
TOTAL				67.17/ton

is a high-sulfur fuel; therefore, sulfur dioxide will be included in the gases going to the melting furnace scrubber. (Low-sulfur fuel was not considered a viable alternative, because of its expected unavailability and its high cost at the plant site.)

The capital cost for the control system for direct coal firing will be slightly higher than that for the coal gasification alternative because of the greatly increased SO_2 scrubbing requirements. On the other hand, direct coal firing does not require the use of a Stretford process. The capital and operating costs for controlling this alternative (Table IV-11) are about the same as the costs of control of the coal gasification alternative except that a greater chemical cost is required to control the greater amount of sulfur dioxide resulting from direct coal firing. The unit cost for controlling direct coal firing is approximately $9.14/ton of glass; whereas, for the base case it is $7.09 and for the coal gasification alternative, $7.68.

b. Water Pollution

The purge rate from the glass furnace scrubber is more than three times the purge rate expected from the other alternatives, primarily because the concentration of sulfates and sulfites is approximately three times higher. The unit cost for wastewater treatment is approximately $1.38/ton of glass, versus $0.64/ton of glass for all of the other alternatives (Table IV-13).

c. Solid Waste Disposal

The solid wastes generated from direct coal firing include the coal ash, the dust from the fabric filter, and the sludge from the water treatment plant, primarily calcium sulfate/sulfite from the SO_2 scrubbing system. The cost for sludge disposal is included with the water treatment costs, and the cost for disposal of the other two solid waste sources is the same as for the other coal alternatives: i.e., $0.01/ton* for the filter dust and $0.18/ton* for the coal ash.

E. COAL-FIRED HOT GAS GENERATION

1. Process Description

Wormser Engineering, Inc., of Marblehead, Massachusetts, is conducting a pilot plant feasibility study on a new direct-combustion system. This system, called COHOGG (coal-fired hot gas generator) (Wormser, Wormser Engineering), has the potential to provide a combusted gas at a temperature sufficient to melt glass. Essentially, COHOGG is a conversion burner that may be substituted directly for oil or gas burners in furnaces, boilers, and other direct heating applications. Virtually all coal types are suitable, including both coking and non-coking types and with high- or low-sulfur coals. If this process is indeed technically feasible, units will have energy outputs consistent with the energy requirements for glass melting.

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*ton of glass

The system (Figure IV-7) generates a hot gas by separating char and volatiles, burning the char, and then mixing its products of combustion with the volatiles and burning them together. A pneumatic conveying system feeds powdered coal to a pyrolyzer, along with limestone or a mixture of limestone and sodium chloride. The coal entering the system is heated, along with the limestone and air, thereby forming a gaseous product (volatiles) and a solid (char). These products are then separated, the char going to a char burner, and the volatiles to an afterburner. From one-third to one-half of the sulfur in the coal is expected to come off in the pyrolyzer as hydrogen sulfide (H_2S). The limestone, in turn, reacts with the hydrogen sulfide, producing water and calcium sulfide (CaS). Unreacted limestone, char and calcium sulfide go to the char burner, which is a fluidized-bed combustor, where the remaining sulfur forms SO_2. Here the remaining limestone from the pyrolyzer step reacts with the SO_2, forming calcium sulfate which leaves the bed along with the ash from the char. In the fluidized-bed reactor, excess air is mixed with the combustion air to maintain the temperature of the fluidized bed at about 1600°F. The gases from burning the char leave the fluidized bed reactor and are combined with the gaseous products, or volatiles from the pyrolyzer, and burned along with excess air in the afterburner. The outlet temperature of the gases leaving the afterburner is 3000°F. A modification using steam allows a temperature of 3500°F to be realized.

The intent then would be to "pipe" these hot gases from the COHOGG system to the glass melting furnace. Out of necessity, the COHOGG system will have to be reasonably close to the glass melting furnace. Details as to exactly how to feed and play these hot gases over the glass batch are not known at this time.

Theoretically, this approach to glass melting appears to be feasible. A potential drawback of the process, which might also hinder its acceptability in the glass industry, is the absence of a luminous flame. Some people in the glass industry believe that a luminous flame is necessary for greater melting efficiency; others do not. The literature is quite confusing in this area; conflicting data and views are reported. At glass melting temperatures, the crown temperatures seem to be of sufficient magnitude to greatly reduce, if not eliminate, any beneficial effects in increased melting efficiencies from a luminous flame.

Practically, because the system is still in a pilot plant debugging stage, it is unlikely that any glass company would seriously consider adopting the process within the next 10-15 years.

2. Energy Considerations

As mentioned previously, for purposes of comparison we have used throughout our analysis a coal with a fixed heating value, sulfur and moisture content. In view of the present stage of development of this hot gas approach to melting glass, no data are yet available as to its energy requirements; therefore, we use value equivalent to that for natural gas firing, 6.8×10^6 Btu/ton. To melt glass at a 200 tpd rate, the minimum daily coal requirement of the burner will be 61 tons, i.e.:

$$\frac{(200)\quad(6.8 \times 10^6)}{11,100} \times \frac{1}{2000} .$$

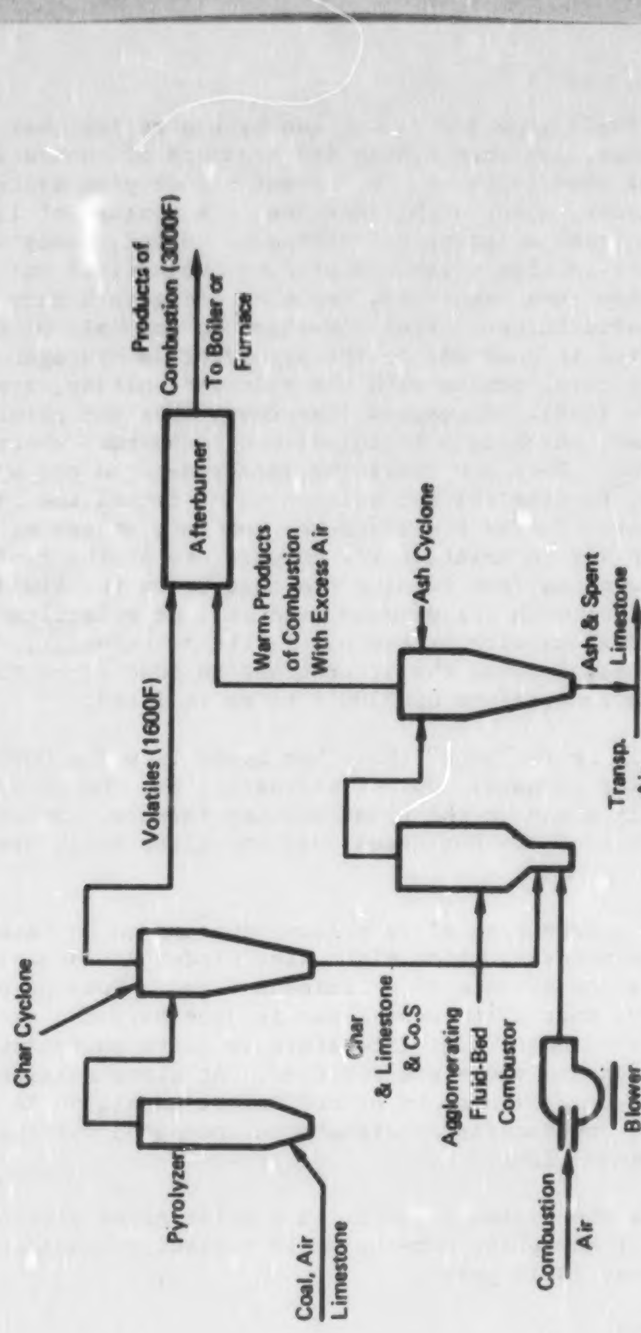
Products of Combustion (3000F)
To Boiler or Furnace
Afterburner
Volatiles (1600F)
Warm Products of Combustion With Excess Air
Ash Cyclone
Ash & Spent Limestone
Transp. Air
Char Cyclone
Pyrolyzer
Char & Limestone & Co.S
Agglomerating Fluid-Bed Combustor
Blower
Combustion Air
Coal, Air Limestone

Figure IV-7. Flow Chart for Industrial COHOGG

To allow for inefficiencies in the hot gas process, we chose a system consuming 77 tons of coal per day, based on our estimate of an overall efficiency of of 80%.

3. Economic Considerations

Because this system is still in the pilot plant debugging stage, a true cost estimate which involves capital cost for retrofitting present glass tanks is highly unrealistic. Therefore, we do not consider the costs associated with "piping" the hot gases and retrofitting the glass furnaces, but we do show both capital investment and operating costs for this system as add-ons to the cost of natural gas-fired, side port, regenerative furnace.

a. Capital Investment

We estimate that the capital costs for coal-fired hot gas generation will increase by $1,560,000, or 211%, over those of the base case. This increased investment has an overall effect of increasing the production costs by $2.16 per ton of glass melted.

b. Production Costs (Table IV-15)

(1) Raw Materials

The raw materials costs for this process are expected to remain essentially unchanged from those of the base case.

(2) Energy

On the basis of our assumptions, we estimate that energy costs for this process will be identical to the coal gasification process, hence a fuel cost savings of 43% relative to the base case.

(3) Labor

We have estimated that this coal process will use somewhat less direct labor and supervisory labor, plant overhead, and payroll overhead than the coal gasification process. However, an estimated increase of $5.85 per ton of glass, or 210%, is expected relative to the base case.

(4) Maintenance Labor and Supplies

Because of the increased capital equipment cost associated with the hot gas generator, an increase estimated at $0.78 per ton of glass will be incurred relative to the base case, or an increase of 45% in maintenance-associated costs.

(5) Miscellaneous Variable Cost

We estimate a 400% increase in this category, which equals $5.37 per ton of glass. Overall, we estimate that conversion to coal-fired hot gas generation will increase the glass melting cost by $12.50 per ton, or about 17%, over the base case.

TABLE IV-15

PRODUCTION COST ESTIMATE: COAL-FIRED HOT GAS GENERATION

Product: Soda-lime Container Glass

Daily Capacity: 200 tons

Annual Production: 65,700 tons

Location: East North Central

Fixed Investment: $1,360,000 plus $1,404,600

	Units Used in Costing or Annual Cost Basis	$/Unit	Units Consumed per Ton of Product	Cost per Ton of Product ($)
VARIABLE COST				
Raw Materials & Shipping Costs				
• Sand	Net ton	20	0.758	15.16
• Feldspar	Net ton	34	0.072	2.45
• Dolomite	Net ton	63	0.132	8.32
• Limestone	Net ton	20	0.116	2.32
• Soda Ash	Net ton	68	0.263	17.88
Energy				
• Purchased Coal	Net ton	20	0.38	7.60
• Electricity	kWh	0.0205	19	0.39
Water				
• Process	1000 gal	0.20	0.00275	0.00
• Cooling	1000 gal	0.03	0.275	0.01
Direct Operating Labor	Man-hour	5.03	0.70	3.52
Direct Supervisory Labor	Man-hour	7.29	0.08	0.58
Maintenance Labor	--			1.25
Maintenance Supplies	--			1.25
Labor Overhead	--			1.87
Miscellaneous Variable Cost	--			6.75
TOTAL VARIABLE COST				69.36
FIXED COST				
Plant Overhead				2.67
Local Taxes & Insurance				0.90
Depreciation				3.22
TOTAL FIXED COST				6.79
TOTAL PRODUCTION COST				76.15
RETURN ON INVESTMENT				9.02
TOTAL				85.17/ton

4. Environmental Considerations

a. Air Pollution

The only difference between the coal gasification alternative and that of heating the glass melting furnace with a hot combustion gas is that the sulfur control in the latter option is inherent within the process itself and is not required as a part of the pollution control apparatus. The gas volumes to the glass furnace are higher with the COHOGG process because of the efficiency losses inherent in the system. Except for the slight size difference, however, the pollution control system for the glass melting furnace itself will be the same as for coal gasification (see Section C of this chapter and Tables IV-11 and IV-12).

b. Wastewater Treatment

The pollutants from the glass melting furnace are the same for this process as they are for the base case; therefore, the wastewater treatment costs will be the same, i.e., $0.64/ton of glass (Table IV-13).

c. Solid Waste Disposal

In addition to the ash from the coal, this alternative has solid waste stream in the form of calcium sulfate, approximately 40 lb/ton of glass, or 1460 tons per year. The corresponding disposal cost at $5.00/ton is approximately $7300, or $0.10/ton of glass. Hence, the total solid waste disposal cost for this alternative is approximately $0.29/ton of glass

F. ALL ELECTRIC MELTING

Electric melting of glass has greatly expanded over the past 25 years. About half of the container glass manufacturers in the United States have electric boosters, and at least 100 all-electric furnaces, ranging in size from 4 to 140 tpd, are in operation through the world (Penberthy, 1974).

1. Process Description*

Molten glass can be heated by the passage of an electric current. Both the design and the operation of an all-electric glass melting furnace differ greatly from the typical natural gas-fired regenerative furnace. The electric furnace, without its regenerative checker structure, is a much simpler design. Electric furnaces may be classified as either "hot top" or "cold top." The "hot top" furnace is really an electric furnace with gas boosting, which may be referred to as a mixed-melt furnace. The "cold top" furnace is the type of design used in all-electric melting. In this design, after heat-up (by gas or oil) the superstructure is completely or partially removed.

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*(Penberthy, 1974; Loesel, 1975)

The most common type of "cold top" has one end wall of the superstructure removed for charging by a conveyor. The batch layer covering the melter is continuously renewed by the feeding on of fresh batch over the whole surface. The raw materials are conveyed, or charged, so that as the batch is progressively covered by successive layers, it heats up gradually, thereby allowing the glass melting reaction to occur in sequence. This is quite unlike a fuel-fired furnace, where the batch is subjected to a high temperature upon its introduction to the furnace. The gas emitted from an electric glass melting furnace consists almost entirely of water vapor and carbon dioxide.

Control of the batch blanket is critical to the operation of the all-electric melter. Usually a 3- to 6-inch blanket is maintained. Inadequate control of the blanket may lead to bridging or blow holes. Bridging occurs when a semi-hard crust forms out to the side walls. This causes the molten glass level to decrease, thereby forming a pocket of trapped gases. The level will continue to decrease until the crust is broken. Sometimes forehearths have been drained before this condition was noted. Blow holes are formed due to hot spots or areas in the molten glass batch blanket. In these areas the glass has a lower resistivity; therefore, it develops greater current densities, which in turn produce a still hotter area. If not controlled, a runaway condition could occur, causing damage to the refractories and possibly a furnace failure.

The latest all-electric glass melting furnaces use vertically positioned molybdenum rod electrodes. The rods are held in place by water-cooled holders whose main function is to freeze the glass in place around the electrode so that it will not be pushed out by pressure and to reduce the surface temperature of the molybdenum to minimize oxidation. The water-cooled holder for each rod electrode is built into the refractory floor of the furnace, which is itself raised above the floor level in the vicinity of the electrodes. This patented arrangement permits construction of deeper furnaces than is possible with horizontal electrodes. It also permits the depth of the batch crust covering the surface of the melt to be controlled by raising or lowering the electrodes to the height required. Thus the crust of cold raw materials on the surface of the melt can be maintained as an additional insulation while its actual thickness can be controlled to meet specific requirements.

At the same time, the paired electrodes can be located in a horizontal plane to ensure that each is adequately remote from the refractory side walls of the melting chamber. If the electric energy introduced from the electrodes into the melt can be largely contained within the confines of the electrode configurations, the molten glass outside the configurations acts as a first layer of thermal insulation to the melt. More important, being relatively viscous by comparison with the molten glass within the electrode configuration, it acts as a protection to the refractory lining. The advantage of vertical rod electrodes has been borne out in practice and, not only has the erosion of the refractory lining been considerably reduced with a comparative increase in campaign life, but the absorption of molybdenum into the glass has also decreased.

2. Energy Considerations

In both the opened and closed "cold top" furnace, the batch blanket thickness is important in conserving energy and in minimizing emissions. A thick blanket insulates better and retains more of the radiant heat deeper in the blanket, hence uses less energy. However, as mentioned above, too thick a blanket can lead to bridging.

The efficiency of electrically melting glass has been argued about for years. Electric furnaces are known to utilize 65-80% of the direct heating energy, compared to 15-20% efficiency for natural gas-fired furnaces. The power consumption in a large all-electric furnace melting soda-lime container glass is expected to be about 780 kWh per ton. This figure will vary somewhat according to the percentage of cullet used in the batch, maintenance and thickness of the batch cover, method of batch charging, and the age of the furnace and how well it is insulated. In comparing the electrical power consumption requirements to melt glass electrically versus natural gas firing, consideration should also be given to the efficiency factor for generating and transmitting electrical power. Hence, at 780 kWh per ton on an equivalent Btu or fossil-fuel basis, this would be

$$780 \times 10{,}500 = 8.19 \times 10^6 \text{ Btu/ton,}$$

which is actually 20 percent more Btu per ton than used for glass melted in a natural gas-fired, side port, regenerative furnace.

3. Economic Considerations

a. Capital Investment

For furnaces having no pollution control equipment, we have estimated that capital costs for an all electric furnace will be about 15% higher, $219,400, than for a natural gas-fired, side port, regenerator furnace. The added capital cost for pollution equipment and its installation (discussed in a separate section of this report) on an electric glass melting furnace will directly increase the production cost by $0.30 per ton.

b. Production Costs (Table IV-16)

(1) Raw Materials

The cost of the major ingredients in the glass batch for electric melting will remain essentially unchanged relative to those for the base case.

(2) Energy

On the basis of our operating assumptions and assumed fuel costs, we estimate that the energy cost entailed in using electrical energy to melt glass will be greater than that with natural gas. This increase is predicated

TABLE IV-16

PRODUCTION COST ESTIMATE: ALL-ELECTRIC MELTING

Product: Soda-Lime Container Glass
Daily Capacity: 200 tons
Annual Production: 65,700 tons

Location: East North Central
Fixed Investment: $1,626,000

	Units Used in Costing or Annual Cost Basis	$/Unit	Units Consumed per Ton of Product	Cost per Ton of Product ($)
VARIABLE COST				
Raw Materials & Shipping				
• Sand	Net ton	20	0.758	15.16
• Feldspar	Net ton	34	0.072	2.45
• Dolomite	Net ton	63	0.132	8.32
• Limestone	Net ton	20	0.116	2.32
• Soda Ash	Net ton	68	0.263	17.88
Energy				
• Electricity	kWh	0.0205	780	15.99
Water				
• Process	1000 gal	0.20	0.00275	0.00
• Cooling	1000 gal	0.03	0.275	0.01
Direct Operating Labor	Man-hour	5.03	0.21	1.06
Direct Supervisory Labor	Man-hour	7.29	0.02	0.15
Maintenance Labor	--			1.24
Maintenance Supplies	--			1.24
Labor Overhead	--			0.86
Miscellaneous Variable Cost	--			0.91
TOTAL VARIABLE COST				67.59
FIXED COST				
Plant Overhead				1.23
Local Taxes & Insurance				0.49
Depreciation				1.77
TOTAL FIXED COST				3.49
TOTAL PRODUCTION COST				71.08
RETURN ON INVESTMENT				4.94
TOTAL				76.02/ton

on an increase in the cost of natural gas to \$2.06 per 1000 ft^3 and a cost of electric power of \$0.0205 per kWh. Also, if one considers efficiencies in generating electric power and losses in transmission, on a Btu basis, it takes more energy to melt glass electrically than it does by natural gas firing. We have estimated an additional energy cost of \$1.60 per ton, or 11%, to melt glass electrically than with natural gas.

(3) Labor

We estimate that there will be only an incremental increase in direct labor and its associated costs. We estimate that direct labor will increase by about \$0.10 per ton, which in turn causes an overall labor associated cost increase of \$0.51 per ton, or 18%, relative to the base case.

(4) Maintenance Labor and Supplies

Maintenance costs are expected to increase somewhat, primarily because of the cost associated with the electrodes. We estimate that the annual cost will be about 10% of the melter cost, or \$2.47 per ton, versus 6% for the natural gas case. This is \$0.75 per ton, or a 44% higher maintenance cost than the base case.

(5) Miscellaneous Variable Costs

The costs associated with this category will be somewhat lower for electric melting than for the base case because low vaporization losses reduce the cost of many of the minor batch ingredients. Hence, we estimate this cost at 2% of the raw materials cost, versus 3% for the base case, for a decrease of \$0.47 per ton of glass.

4. Environmental Considerations

a. Air Pollution

The option to electrically heat glass melting furnaces results in a shift in the environmental problems from the furnace to the electric power plant. In this case, the only exhaust from the glass melting furnace is from the decomposition of carbonates, sulfates, nitrates, etc., in the glass batch. The exhaust will be almost entirely CO_2, with approximately 3 lb of SO_2/ton of glass.

The control system for this exhaust is identical to the one used for the base case and for coal gasification, but the size of the system is considerably less because of the greatly reduced exhaust volume. The unit cost of control for this alternative is only \$2.12/ton of glass, versus \$7.09 required to control the base case (Table IV-11). However, there is a control cost associated with the power plant which should be considered. At present, SO_2 scrubbing systems cost about \$100/kW. Since a 200 tpd glass melting furnace requires 6500 kWh/hr, the prorated share of control costs which should be allocated to the glass furnace is about $650,000, or about half of the cost of controls for the other alternatives. Likewise, the annual cost of SO_2 scrubbers is about $0.0033/kWh. Hence, the prorated share of annual costs allocated to the glass furnace would be about $2.57/ton of glass, which is also considerably less than the annual control cost of other alternatives.

b. Wastewater Treatment

The wastewater treatment costs for this alternative are identical to those discussed in the base case (Table IV-13). Note that even though the scrubber gas volume is drastically reduced, the amount of pollutants, such as SO_2, is about the same since these depend upon the composition of the glass batch. The scrubber purge depends upon the amount of these pollutants; and, therefore, the wastewater purge from the scrubber is the same in both cases.

c. Solid Waste Disposal

This alternative generates solid wastes in the form of dust from the fabric filter and coal ash (at the power plant). The dust is the same amount as generated in the base case and the cost of disposal is about $0.01/ton of glass. The coal ash is about the same amount as for the other coal alternatives. The cost of disposal is estimated to be about $0.18/ton of glass.

G. BATCH AGGLOMERATION - PREHEATING

In this country and in Europe a form of batch preheating has been used, but only on a laboratory scale. The intent of preheating was to prereact the batch ingredients, rather than preheating to conserve energy. Relative to energy conservation, Battelle (Schorr, Battelle) has proposed a combination of batch pelletizing and preheating of these pellets by utilization of the waste gases. To our knowledge there are insufficient economic data on large-scale preheating; therefore, only a preliminary engineering cost estimate can be made at this time.

1. Process Description

This approach to energy conservation is not yet commercially viable, and because of the stage of development, processing details are not available (Figure IV-8). It consists of a number of storage bins, each having its own weigh hopper and scale. The raw materials are weighed individually, fed to a collecting belt, and conveyed to a mixer. A pan mixer, or muller, is used to blend the dry powders. Up to this stage the process is identical, or can be identical, to the present processing techniques used by each of the glass manufacturers; after mixing, the processes begin to differ. From the mixer, the blended batch would have to be transferred or conveyed to a surge hopper and weigh feed. Material would then be fed to a pelletizer, where it may be necessary to add water, about four percent by weight, as a binder for the pellets. The pelletized material would next be conveyed through a "high-temperature" continuous dryer which would be heated by the waste gases of

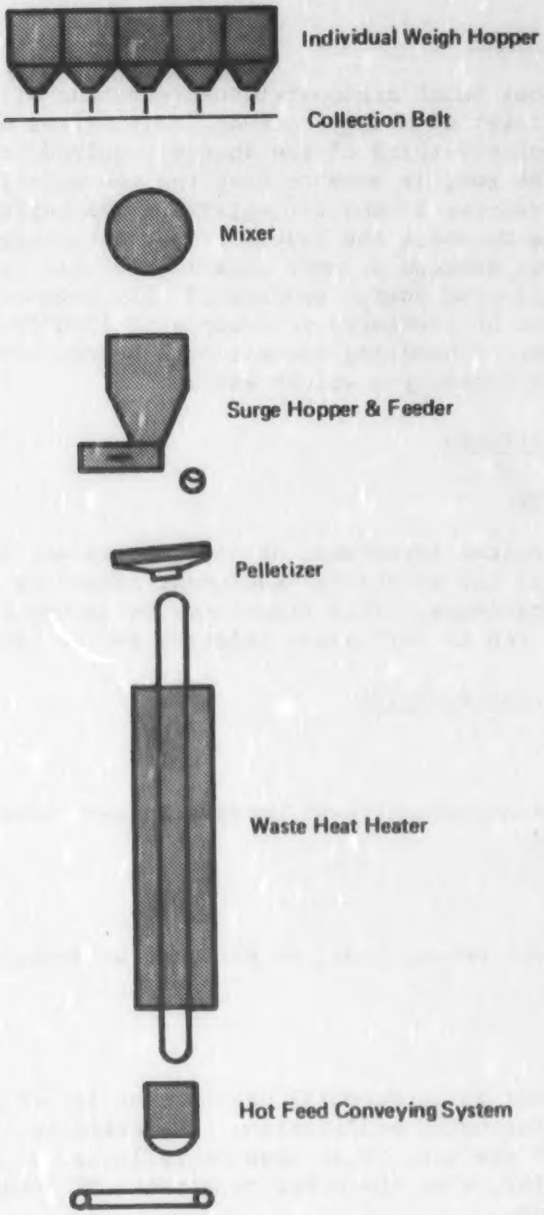
Individual Weigh Hopper
Collection Belt
Mixer
Surge Hopper & Feeder
Pelletizer
Waste Heat Heater
Hot Feed Conveying System

Figure IV-8. General Schematic of Batch Agglomeration - Preheating

the glass melting furnace. Before being fed into the glass tank, the pellets would be heated to about 1290°F, or possibly higher. Although, the processing steps appear quite simple, the details of how to transfer and feed the heated pellets require a great deal of development work.

2. Energy Considerations

It is expected that batch agglomeration-preheating will have a marked beneficial effect in terms of energy consumption in glass melting. As mentioned elsewhere, about one-third of the energy required to melt glass, or about 2.3×10^6 Btu per ton, is used to heat the raw materials to their melting temperature. Therefore, if the raw materials are heated by the waste gases from the furnace to about the 1290°F temperature range, this would correspond to an energy savings of more than 1×10^6 Btu per ton, or about 20%. Battelle has estimated energy savings of 25%; however, this means that the batch would have to be preheated to upwards of 1500°F; and at these temperatures, the problems of handling the material become severely compounded by the fact that it is becoming a sticky solid.

3. Economic Considerations

a. Capital Investment

An increase in capital investment of $500,000 is estimated to be required to purchase and install the additional equipment necessary to pelletize and preheat the batch ingredients. This translates to an overall capital cost increase of $0.68 per ton to melt glass relative to the base case.

b. Production Cost (Table IV-17)

(1) Raw Materials

We do not foresee any significant changes in raw materials costs between this and the base case.

(2) Energy

On the basis of our assumptions, we estimate an energy cost decrease of $1.20 per ton.

(3) Labor

It is expected that an incremental addition of direct labor will be associated with this manufacturing modification. We estimate that direct labor will increase by $0.15 per ton, which then is reflected by an overall increase of $0.41 per ton, or 15%, when the other components of labor are factored into the production cost.

TABLE IV-17

PRODUCTION COST ESTIMATE: NATURAL-GAS-FIRED; BATCH AGGLOMERATION-PREHEATING, SIDE PORT, REGENERATIVE FURNACE

Product: Soda-lime Container Glass

Daily Capacity: 200 tons

Annual Production: 65,700 tons

Location: East North Central

Fixed Investment: $1,905,000

	Units Used in Costing or Annual Cost Basis	$/Unit	Units Consumed per Ton of Product	Cost per Ton of Product ($)
VARIABLE COST				
Raw Materials & Shipping				
• Sand	Net ton	20	0.758	15.15
• Feldspar	Net ton	34	0.072	2.45
• Dolomite	Net ton	63	0.132	8.32
• Limestone	Net ton	20	0.116	2.32
• Soda Ash	Net ton	68	0.263	17.88
Energy				
• Purchased Gas	10^6 Btu	2.06	5.5	11.34
• Electricity	kWh	0.0205	19.0	0.39
Water				
• Process	1000 gal	0.20	0.00275	0.00
• Cooling	1000 gal	0.03	0.275	0.01
Direct Operating Labor	Man-hour	5.03	0.22	1.11
Direct Supervisory Labor	Man-hour	7.29	0.02	0.15
Maintenance Labor				1.02
Maintenance Supplies				1.02
Labor Overhead				0.80
Miscellaneous Variable Cost				1.38
TOTAL VARIABLE COST				57.13
FIXED COST				
Plant Overhead				1.14
Local Taxes & Insurance				0.58
Depreciation				2.07
TOTAL FIXED COST				3.79
TOTAL PRODUCTION COST				67.14
RETURN ON INVESTMENT				5.80
TOTAL				72.94/ton

(4) Maintenance Labor and Supplies

It is estimated that an additional maintenance cost of \$0.31 per ton, or 17%, will be incurred relative to the base case.

(5) Miscellaneous Variable Costs

For this category, we estimate that there will be no significant change.

At a natural gas cost of \$0.93 per 10^6 Btu, batch agglomeration-preheating has essentially the same overall cost as the base case; however, as the cost of natural gas increases, so will the potential savings of this process.

4. Environmental Considerations

a. Air Pollution

The batch preheat technology is an energy conservation technology relating to a furnace modification rather than a method of furnace heating. Hence, this technology is applicable to all of the previously discussed methods of heating (except for electric heating). By improving the thermal efficiency of the furnace, this technology reduces the fuel requirement per ton of glass, thereby reducing the exhaust volume from the glass melting furnace. The reduction in gas volume to the control system correspondingly reduces control costs.

The types of controls used for batch preheating are identical to those described previously for the base case, but the system is smaller because of the increased thermal efficiency of the furnace. The cost of control for this alternative is considerably less than that for other alternatives using coal, and it is approximately the same as the control cost for electric power if the allocated costs for power plant control are included in the cost of control of the glass furnace (Table IV-11).

b. Wastewater Treatment

Even though the gas volume from the scrubber is reduced, the wastewater treatment associated with this alternative is identical to that of the other alternatives because the amount of pollutants, primarily SO_2, is the same in all cases (resulting from the decomposition of materials in the glass batch). The costs for water treating (Table IV-13) have been assumed to be identical with the costs for the base case.

c. Solid Waste Disposal

The costs for solid waste disposal for this alternative depend upon the fuel being used for the furnace. Using natural gas, the costs are the same as the costs for the base case, i.e., 1¢/ton of glass. Using coal, an additional cost of approximately 18¢/ton of glass is required for disposal of the coal ash.

V. IMPLICATIONS OF POTENTIAL PROCESS CHANGES

A. COAL GASIFICATION

1. Impact On Pollution Control/Energy Requirements

In this analysis we assume that the basic glass melting function is similar to present operations using natural gas as the energy form. Although the experience in the industry has been that changes in the energy form do, in fact, change operation conditions, the basic process remains without major alterations.

The primary process modification of the base case (natural-gas-fired, side port, regenerative furnace) is the addition of on-site facilities to produce low-Btu gas through the controlled combustion of bituminous coal. This requires additional capital outlays as well as additional operating cost for the gas producer.

In addition, the composition of the emissions from the glass melting furnace, principally from the high-temperature combustion and the decomposition of the batch, are not expected to be altered; however, higher gas volume will result in higher volume of emission. No additional water effluent streams are created at the glass furnace. The gasification facility itself introduces two new effluent streams: the solid waste stream in the form of ash from the combustion process; and the water purge from the sulfur recovery system on the existing gas stream. The recovery system is essential to remove H_2S from the gas before it enters the glass melting furnace, thereby reducing the load on the furnace scrubbing system.

The sulfur from the recovery system and the ash from the combustion process are assumed to be taken to landfill. The water stream from the sulfur recovery system is estimated to be about 1000 gpd and it is anticipated that contract disposal would be most feasible. The capital cost and annual operating cost associated with the pollution control system are summarized in Table II-2 (which is reproduced here as Table V-1).

Because of the higher gas volumes required due to the additional combustion air requirements, an increase in the capacity of the air emission control system on the glass melting furnace is needed. The increase of about ~3000 scf of gas results in an increased pollution control capital cost of $97,000 and operating cost of $0.59/ton of glass.

TABLE V-1

SUMMARY OF INVESTMENT AND OPERATING COST FOR THE BASE CASE* AND ALTERNATIVE FUEL SYSTEM AND PROCESS MODIFICATIONS

Melting Unit Process	Facilities		Air Pollution Control		Water Pollution Control		Solid Waste Control		
	Glass Furnace	Auxiliary Installation	Glass Furnace	Auxiliary Installation	Glass Furnace	Auxiliary Installation	Glass Furnace	Auxiliary Installation	Total
Natural Gas Firing									
Investment ($000)	1,404	--	1,136	--	95	--	--	--	2,635
Operating Cost***$/ton	72.67	--	7.09	--	0.64	--	0.01	--	80.41
Coal Gasification									
Investment ($000)	1,404	1,380	1,231	1,066	95	--	--	--	5,176
Operating Cost $/ton	91.74		7.68	6.00	0.64	2.50	6.01	0.24	114.81
Direct Coal Firing									
Investment ($000)	1,404	355	1,420	--	192	--	--	--	3,371
Operating Cost $/ton	67.17		9.14	--	1.38	--	0.01	0.21	77.91
Coal-Fired Hot Gas Generation									
Investment ($000)	1,404	1,560	1,420	--	95	--	--	--	4,479
Operating Cost $/ton	85.17		8.93	--	0.64	--	0.01	0.28	95.03
Electric Melting									
Investment ($000)	1,624	--	304	(650)**	95	--	--	--	2,673
Operating Cost $/ton	76.02		2.12	(2.57)**	0.64	--	0.01	(0.18)**	81.54
Batch Preheat with/Natural Gas Firing									
Investment ($000)	1,404	500	951	--	95	--	--	--	2,950
Operating Cost $/ton	72.94		5.18	--	0.64	--	0.01	--	78.77

*Base Case - 200-tpd, Natural Gas-Fired, Side Port, Regenerative Furnace. Costs Reflect only Melting Cost.

**Cost of pollution control at power generation station prorated to glass plant.

***Operating cost $/ton = production cost plus pre tax return on investment @ 20%.

The energy use implication of replacing natural gas with gas from coal gasification is principally one of replacing a low-availability fuel with a less critical and available fuel, i.e., coal. It is anticipated that energy consumption required to melt the glass would remain the same as in the case of natural gas and experience (Tooley, 1974) indicates that a consumption of 0.37 ton of coal per ton of glass is realistic and conservative.

2. Factors Affecting Probability of Change

By far the principal implication for the glass industry is the very significant investment required to build the coal gasification facility. The estimated additional investment of $1.4 million is approximately 12.5% of the estimated total plant investment for a 200-tpd operation. If the further cost of pollution control equipment is considered, the additional annual cost resulting from melting glass using coal gasification is estimated to be $34.40 per ton of glass, an increase of 43%.

This is a substantial increase and would place products like glass containers at a disadvantage to aluminum and steel in the large beverage market. If such costs are not recovered through price increases, the effect on profitability would be large and could affect the viability of a large fraction of the industry.

With these economic factors, it is unlikely that the glass industry will voluntarily move in the direction of coal gasification as an alternative to natural gas.

3. Areas of Research

Since the economic viability of melting glass with gas produced by coal gasification is questionable, further work on the treatment of effluent streams from the gasification process is not warranted. However, as there is presently no proven process for the treatment of the emissions from the glass melting furnace, this area would be a more fruitful one for research. The specific problem of treatment of the emissions from the glass furnace are detailed in the base case environmental consideration section of this report.

B. DIRECT COAL FIRING

1. Impact On Pollution Control/Energy Requirements

In terms of energy conservation, direct firing of glass furnaces with pulverized coal is a utilizaton of a less critical form of fuel than present natural gas processes. Furthermore, direct firing of coal is a more efficient utilization of the heating value of the coal compared with coal gasification and hot gas generation.

The pollution control implications of direct firing with pulverized coal are mainly the increased gas volume in the glass tank and the additional air emission as a result of the SO_2 and ash generated in the combustion process. The increased stack gas flow rates (13-14% greater than in natural gas firing) substantially add to the pollution control cost, making these costs for direct coal firing the highest of all the alternatives considered.

2. Factors Affecting Probability of Change

The technical feasibility of direct firing of the glass melting function with pulverized coal has not been determined. There are two technical areas where problems are anticipated. First, the effect of the ash on the life of the refractories due to the fluxing action of the fly ash could substantially reduce the furnace life; second, reactions between the ash and the refractories may result in excess stones, seeds, etc., in the finished product. No doubt, if this alternative were used, furnace design and operation would have to be altered considerably.

The consistency of coal in terms of heating value, ash content and sulfur would be a major consideration because variable coal feed would make furnace operation difficult and influence the pollution control characteristics.

From an economic standpoint, direct coal-fired furnaces are competitive with natural gas furnaces and appear to be less expensive than coal gasification, coal-fired hot gas generation, and electric melting. The additional capital cost for coal storage, handling, pulverizing and feed is modest; however, the glass furnace would entail additional costs for pollution control.

3. Areas of Research

The feasibility of direct coal-fired glass melting furnaces has not been satisfactorily demonstrated. Whether the entire furnace can be converted to direct coal firing or whether only a portion of the melting is done with coal is questionable because the adverse effect on glass quality is still unanswered.

C. COAL-FIRED HOT GAS GENERATION

1. Impact On Pollution Control/Energy Requirements

The approach to replacing natural gas with a modification of a coal-related process of this nature has not been reduced to practice. The system is in an early stage of development and scaled pilot systems are only now being considered. Obviously, there are little data upon which to draw conclusions as to the viability of this approach as an alternative in glass melting.

In this process the hot (3000°F) gas is generated by separating the char and volatiles, burning the char, and recombining the products of combustion and burning them together. The principal emission stream generated in this on-site facility is the ash and spent limestone from the fluidized-bed combustor. There appears to be no water or air emission from the generator. The cost of solid waste removal is estimated to be $0.29/ton of glass.

It is visualized that with some changes to permit the gas to be introduced under control the hot gas can be used in a typical side port, regenerative glass furnace. Because of the increased gas volume involved due to the efficiency of the system, there is some increase in the air pollution control requirement for the furnace glass tank. It is anticipated that no changes in type or composition of the particulate or gas emissions from the glass batch will take place. The cost of air pollution control using the coal-fired hot gas generator is estimated to be $8.93/ton versus $7.09/ton of glass in the base case.

No additional water effluent streams are associated with the hot gas generator nor are there any further requirements for process water at the glass melting furnace.

We assume that the energy requirement for melting glass is 6.8 x 10^6 Btu/ton, and 0.37/ton of coal with a heating value of 11,100 Btu/lb will be required to melt a ton of glass. Energy conservation is implied in that the hot gas generation process uses a less critical fuel, coal, to replace a critical one, natural gas.

2. Factors Affecting Probability of Change

The most important questions are the reliability of a scaled system of the size required for glass melting, and the adaptability of this technique to the melting of glass. The importance of a luminescent flame in the melting process is not clear and there is no doubt that furnace design modifications would be required and operating practice would be altered.

Estimates of the capital investment indicate that the cost of $1.56 million to provide an on-site facility essentially equal the cost of the glass melting furnace (without pollution control equipment). The hot gas generator does not add significantly to the cost of pollution control; however, the larger gas volumes at the glass melting furnace increase the size of the air emission control system. This fuel form results in an overall increase in operating cost of $14.62/ton, or 18%, relative to the base case.

3. Areas of Research

At this time, the adaptation of the coal-fired hot gas generator to the glass melting process is questionable. The potential that this alternative has to replace the conventional natural gas process can only be determined from more extensive operating information and development works. It is estimated that this alternative can be considered for the very long term.

The process does not introduce any new areas that would require research on control of the effluent streams.

D. ELECTRIC MELTING

1. Impact On Pollution Control/Energy Requirements

Although the size of present-day furnaces is small, electric melting of glass is being done. The melting process using electricity is significantly different from that using fossil fuels. In electric melting the heat is generated directly in the glass melt itself rather than the heat being applied above the melt and relying on radiation as the principal heat transfer mechanism. The cold top implies that the top of the glass melt is covered by the raw batch, thus reducing the high heat losses from the hot melt. Melting of the batch takes place at the melt-batch interface.

The pollution implications of cold top electric melting have been clear for some time. Since no combustion takes place in the air atmosphere above the melt, NO_x is not created, and any possibility of SO_x from fossil fuel is also eliminated. Although decomposition of the batch ingredients, such as sulfates, nitrates, carbonates, etc., will still be a source of air emission, dusting due to the entrainment of batch ingredients in the high-velocity flames of fossil fuel-fired tanks is eliminated. Electric melting does not introduce any additional water effluent streams.

Basically, the volume of gaseous emissions from an electric melting furnace is only a fraction (~4%) of the emissions from a similar fossil fuel-fired furnace. Therefore, the likely requirements for air emission controls on a 200-tpd electric furnace are $304,000, versus $1,136,000 for a natural gas-fired furnace.

The cost of electric melting appears to be comparable to that of a natural gas-fired furnace. Electric melting costs are estimated to be less than those associated with other forms of energy, such as coal gasification and coal fired hot gas generation.

By using the alternative of electric melting, a more available form of energy replaces a less available one and this can be considered a form of energy conservation. No overall reduction in the environmental problem and control is anticipated, since this approach essentially shifts the environmental problems and pollution control from the glass furnace to the electric power station. In the cost comparison a portion of the environmental control cost at the power plant was prorated and assigned as a cost of electric melting.

2. Factors Affecting Probability of Change

One of the major factors that would inhibit the glass industry's broad adoption of electric melting is the availability of sufficient power generating capacity in areas where glass is manufactured. The high capital investment required and the lack of capital at reasonable cost has inhibited the expansion of electric power generation capacity.

Another major hurdle is the feasibility of construction of large (>200-tpd) electric furnaces; present-day furnaces are of the order of 100 tpd. Before one can predict the possibility of electric melting in large plants producing flat glass or containers, considerably more information and experience is required.

3. Areas of Research

The feasibility of developing electric glass melting furnaces of larger than present electric melters needs to be studied. The development of a "proven air emission control" system for the lower emission values of this type furnace would be highly desirable.

E. BATCH PREHEATING

1. Impact On Pollution Control/Energy Requirements

The alternative of batch preheating is somewhat different than the other approaches since the fuel form does not change. Instead, this approach uses heat from the melting process to preheat the batch ingredients to some fraction of the glass melt temperature. It is estimated that a preheat temperature of 1300°F would reduce the energy consumption in the furnace by about 20%. In a sense, batch preheating could be used with all of the alternative approaches to melting glass that we have reviewed except electric melting.

The pollution control implications in batch preheating are the significantly lower stack gas flow rates and, consequently, smaller volumes of air effluent to handle, thus significantly reducing the cost of control. The batch preheat process produces no additional water streams. As a result, the additional cost due to pollution control is $5.83/ton of glass, about 25% less than control costs for the base case.

2. Factors Affecting the Probability of Change

Utilization of the batch product will require confirmation of the calculated energy savings. At this time, neither the technical nor economic feasibility have been demonstrated. It appears as if the capital cost might be modest; however, this must be confirmed after technical feasibility has been demonstrated.

Whether existing glass plants could implement the technology, once it is determined feasible, would depend on specific plant situations. Space limitations may make it difficult to alter the in-line process.

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APPENDIX A

INDUSTRY STRUCTURE - GLASS MANUFACTURING

1. DESCRIPTION

a. Industry Sectors

The manufacturing of glass and glass products in the United States is a large, widely diversified industry. The Standard Industrial Classification (SIC) is a helpful but not exclusive guide for segmenting the glass industry. The greater portion of manufactured glass products falls under the SIC 3-digit classifications 321 and 322. However, an important segment of the U.S. glass industry is the manufacture of glass wool products, which is listed in SIC 3296. Another consideration in defining the industry segment of highest priority in this discussion is the relative energy consumption; therefore, those manufacturing processes involved in producing products from purchased glass and those that require relatively minor quantities of energy are of less interest.

To effectively examine the energy-intensive, large-volume production of glass, we have viewed the industry more in terms of its structure than its SIC numbers. Thus, the segments of the industry have distinct products, sell into different markets, have different technology, and involve specific companies.

The segments of the glass industry covered in this discussion are:

Flat Glass - (SIC 3211) including sheet, plate and float, laminated, tempered automobile glass

Glass Containers - (SIC 3221) food, beverage, pharmaceutical glass

Pressed & Blown Glass - (SIC 3229) tableware, T.V. bulbs, lamp enclosures, tubing, etc.

Fiber Glass - (SIC 3229 and 3296) continuous textile-grade and wool fiber glass

b. Flat Glass Segment*

The production of sheet, plate and float glass in the United States is highly concentrated and involves only seven companies (Table A-1). More than 87% of the U.S. output of sheet glass is produced by PPG Industries (PPG), Ford Motor Company, Libby-Owens-Ford (LOF), and ASG Industries (ASG). These four companies plus Guardian Industries and C-E Glass (a subsidiary of Combustion Engineering) are the only producers of float glass.

In summary, three firms largely dominate U.S. production of plate glass. Two, PPG and LOF, are large, multiproduct firms producing a wide range of flat glass products, including rolled and tempered as well as other industrial products. They also participate in the foreign production of flat glass through arrangements ranging from process licensing agreements and joint ownership of foreign facilities. The third major company, Ford, produces float and tempered glass primarily for its own vehicles, but also for sale to the trade.

Two smaller firms, ASG and Fourco Glass Company, also are fairly significant. ASG produces sheet, float and rolled glass (as well as tempered architectural glass); Fourco's production is limited to sheet glass. Finally, Guardian, while a substantial processor of laminated and tempered automotive glass, only commenced the production of float glass in 1970; C-E Glass did so only as recently as 1971.

In addition to Guardian Industries, Ford, LOF, and PPG are manufacturers of raw glass as well as fabricators of laminated and tempered automotive glass. These four companies, plus Chrysler, which purchases raw glass and fabricates it for use in its automobiles, probably account for more than 80% of automotive glass manufactured in the United States; the remainder is produced by three small independent companies, Shatterproof Glass Corporation, Safelite Industries, and Safetee. Shatterproof produces both laminated and tempered glass; the other two companies are only laminators. All three companies purchase raw glass from the major producers for further processing.

LOF is the largest automotive glass fabricator, serving along with PPG, General Motors' needs. Shatterproof, Guardian and other small companies mainly supply the replacement market.

c. Glass Containers**

The glass container industry in the United States is large, employing more than 70,000 persons and producing products valued at more than $2 billion in 1972. Its total employment is three times and the value of its shipments is nearly four times that of the flat glass industry.

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*Arthur D. Little, Inc., 1973.

**Arthur D. Little, Inc., 1975.

TABLE A-1

FLAT GLASS COMPANIES BY TYPE OF PLANT AND LOCATION

	Type of Plant				
Company	**Sheet**	**Plate**	**Float**	**Laminating**	**Tempering**
ASG	Jeanette, Pa. Okmulgee, Okla.	Kingsport, Tenn.	Greenland, Tenn.		
Combustion Engineering			*Floreffe, Pa. Almonesson, N.J.		
Chrysler				Detroit, Mich.	Detroit, Mich.
Ford			Dearborn, Mich. *Nashville, Tenn. Tulsa, Okla.	Dearborn, Mich.	Nashville, Tenn.
Fourco	Clarksburg, W. Va. (2) Ft. Smith, Ark.				
Guardian			Carleton, Mich.	Detroit, Mich.	Millburg, Ohio
LOF	Charleston, W. Va.	Rossford, Ohio	Toledo, Ohio Ottawa, Ill. Lathrop, Cal. Rossford, Ohio **Laurinberg, N.C.	Toledo, Ohio Ottawa, Ill. Lathrop, Cal.	Toledo, Ohio Ottawa, Ill. Lathrop, Cal. Rossford, Ohio
PPG	Henryetta, Okla. Mt. Vernon, Ohio Clarksburg, W. Va. Mt. Zion, Ill. Fresno, Cal.	Cumberland, Md.	Cumberland, Md. Meadville, Pa. Crystal City, Mo. Carlisle, Pa. *Wichita Falls, Tex.	Creighton, Pa. Greenburg, Pa.	Crestline, Ohio Tipton, Pa. Carlisle, Pa.
Safelite				Wichita, Kan. Enfield, N.C.	
Safetee				Phila., Pa.	
Shatterproof				Detroit, Mich.	Detroit, Mich.

* Under construction
** Planned 1974

The glass container manufacturing industry comprises approximately 30 firms operating a total of about 130 plants (Table A-2). However, the eight largest firms account for two-thirds of the plant locations and about 78% of the total industry shipments.

Nine large firms dominate this business. Among the major firms in this industry segment is Owens-Illinois, with annual sales in 1972 of $1.6 billion, of which domestic glass containers account for 62% ($992 million). The company is a major producer of plastic and paper packaging, technical electronics, and consumer glassware, paper, and plastic products. It operates 20 glass container plants in 14 states and participates in a variety of operations.

Brockway Glass Company produces glass containers, with total sales of $236 million in 1972. It operates 14 glass container plants in 11 states.

Glass containers constituted 66% ($158 million) of Anchor-Hocking sales of $240 million in 1972. It operates nine glass plants in eight states.

Other major producers in the glass container industry are Chattanooga Glass Company, Glass Container Corporation, Kerr Glass Manufacturing Company, Thatcher Glass and Metro Containers.

Glass container manufacturing plants are spread throughout the country to service the requirements of regional customers. While these plants are in virtually every area, they are largely concentrated in the East, North, Central and Middle Atlantic states, near industrial centers.

d. Other Pressed and Blown Glass Manufacturing*

According to the SIC, there are more than 50 different product lines in this segment of the industry. However, the major products in terms of dollar value and total production volume are household tableware, lamp enclosures, T.V. bulbs, and glass tubing.

According to the 1972 Census Reports, the total shipments of glass tubing were $55 million, largely in tubing for fluorescent and neon lighting. The major producers of glass tubing are very large multiproduct firms, but these products are not a significant portion of their total business (Table A-3). Much of the tubing is produced by captive operation, i.e., the tubing being made into finished products by the same company (General Electric, Westinghouse, Sylvania). Major companies such as Corning and Owens-Illinois are leading merchant manufacturers of tubing. These companies are also the leading producers of scientific glass tubing.

The total shipments for lamp enclosures, including incandescent lamp envelopes, television tube envelopes, and electronic tube parts, was $253 million in 1972. Of this total, it is estimated that T.V. envelopes accounted for about two-thirds, electronic tubes for one percent, and

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*Arthur D. Little, Inc., 1975.

TABLE A-2

GLASS CONTAINER MANUFACTURERS

Company	No. of Plants	Major Products
Anchor Hocking	9	General line, also tableware
Arkansas Glass Container	1	General line
Ball Corporation	4	General line
Bartlett Collins, Corp.	1	Private mold, also tableware
Brockway Glass Co.	14	General line
Castle-Hanson (Seneca Food Corp.)	1	Food containers
Chattanooga Glass Co.	6	Beverage, food, cosmetics, beer
Columbia Glass Co.	1	Cosmetic, chemical, drugs
Columbine Glass Co.	1	Beer
Diamond Glass	1	Cosmetic, drugs
Gallo Glass Co.	1	Wine bottles
Glass Container Corp.	14	General line
Glenshaw Glass	2	Jars, wide and narrow mouth
Hillsboro Glass	1	Liquor
Industrial Glass Co. (Tropicana)	1	Jars, narrow and wide mouth
Kerr Glass Mfg. Co.	10	General line
Latchford Glass	1	General line
Indian Head	7	General line, wine
Liberty Glass	1	Beverage, milk, juice
Lincoln Container Co.	1	Beer, liquor, private mold
Metro Glass Div., (Krattco Corp.)	4	Flasks, jars, bottles
Midland Glass Co.	3	Beer, food chemicals, preserves
National Bottle Co.	4	Liquors, food, chemicals
National Can Co.	3	General line
Owens-Illinois	20	General line
Thatcher Glass	7	Flasks, jars, jugs, narrow and wide mouth
Underwood Glass	2	Flasks, jars, jugs, beverage, narrow and wide mouth
Wheaton Glass	1	General line
Others not identified	8*	

*Estimate

Source: Arthur D. Little, Inc., estimates.

TABLE A-3

MAJOR GLASS TUBING MANUFACTURERS

Company	Glass Tubing Products	Glass Tubing Plants	Production (tpd)
Corning Glass Works	Pyrex brand tubing.	Parkersburg, West Virginia	
	Corning brand products--fluorescent and thermometer tubing.	Corning, New York (Fall Brook Plant).	
		Other plants where tubing is not major product:	
		Blackburg, Virginia	7.5
		Danville, Kentucky	112.0
		Central Falls, Rhode Island	107.0
		Wellsboro, Pennsylvania	97.0
Demuth Glass Division	Glass tubing and rod in bulk, vials, ampoules, heavy and light wall cylinders, culture and test tubes, pipettes.	Parkerburg, West Virginia	
GTE Sylvania	Glass tubing for fluorescent lights.	Greenland, New Hampshire	NA
		Versailles, Kentucky	
General Electric Company	Glass tubing for fluorescent lights.	Logan, Ohio	110.0
		Jackson, Mississippi	65.0
		Bridgeville, Pennsylvania	44.0
		Bucyrus, Ohio	NA
Owens Illinois	Glass laboratory ware, tubes for electronic and industrial uses.	Kimble Products, Vineland, New Jersey	
Westinghouse Electric	Glass tubing for fluorescent lights.	Fairmont, West Virginia	150,000 pieces
Wheaton Industries	Laboratory, technical and votive glassware.	Millville, New Jersey	

incandescent lamps for ~33%, or $84 million. Five major companies produce incandescent lamp enclosures; two of them, Westinghouse and General Electric, are captive producers (they also manufacture the complete light bulb). Corning is a merchant producer which sells to manufacturers of light bulbs, such as Sylvania.

Corning and Owens-Illinois are the principal manufacturers of television tubes in the United States. Additional captive capacity exists in the RCA plant in Circleville, Ohio. Only color funnel and face plates are being manufactured in the United States in substantial quantities. Corning and Owens-Illinois are integrated multiproduct glass companies.

e. Fiber Glass*

The U.S. production of textile fiber glass products is dominated by four firms. Two, Owens-Corning Fiberglass and PPG Industries, account for about 80% of the total capacity of 750 x 10^6 lb/yr. The other two, Johns-Manville and Certain-Teed, account for approximately 13% of the total. Five other producers divide the remaining 7%. OCF is principally a fiber glass producer, manufacturing both textile and wool glass products. PPG is a large integrated chemical company that produces flat glass as well as textile fibers. Most of the other firms in this business are divisions of integrated companies.

Owens-Corning is also the dominant producer of glass wool fiber and with Johns-Manville has nearly 90% of the U.S. production. The only significant additional capacity is that of Certain-Teed in three plants. Since the economical production of glass wool is a high-volume operation, there are no small producers in this industry segment. Johns-Manville and Certain-Teed are integrated multiproduct companies. The total U.S. capacity is close to 1.8 x 10^9 lb/yr.

2. PLANT CHARACTERISTICS

Because of the diversity in product and type of process used, and considering the long history of this industry and that of its subsegments, the industry is difficult to categorize: in some segments the number of plants is large and plant capacities are not disclosed. Therefore, we use a typical or average plant to characterize each of the industry's subsegments (Table A-4).

Flat glass production is usually a high volume operation with float plant capacities reaching 1500 tons/day (Arthur D. Little, Inc., 1973). Both float and sheet are continuous operations and have production speed of 225-400 ft/hr for sheet production and up to 1500 ft/hr for float plants. Yields are usually a little higher in sheet operations but float processing is more economical. Laminating and tempering operations are most often separated from

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*Arthur D. Little, Inc., 1972.

TABLE A-4

TYPICAL PLANT CHARACTERISTICS

Industry Segment	Location	Age (yrs)	Capacity	Glass	Sales Revenue/Plant ($\$10^6$)
Flat Glass					
Float	Pa. - Ohio	10	400,000 tpy	Soda-lime	72.
Sheet	Ohio	30 - 35	165,000 tpy	Soda-lime	29.
Laminated	Mich.	25	$18.0 \times 10^6 ft^2/yr$	Soda-lime	26.
Tempered	Mich.- Ohio	30	$37.5 \times 10^6 ft^2/yr$	Soda-lime	18.7
Glass Container	East North Central	15 - 20	75,000 tpy	Soda-lime	14.
Pressed & Blown					
Tubing	Mid-Atlantic	30	30,000 tpy	Borosilicate	12.
T.V.	Ind.- Pa.- NY	10	85,000 tpy		35.
Incandescent lamp	Ohio - Pa.	25	65,000 tpy	Soda-lime	30.
Machine Ware	Ohio - Pa.	35	55,000 tpy	Soda-lime Borosilicate Lead	
Fiber Glass					
Textile	S.C. - N.C. - Tenn.	15	45×10^6 lb/yr	Low alkali Borosilicate	15.
Wool	Ohio - Kan.- N.J.	20	50×10^6 lb/yr	Borosilicate	15.

Source: Arthur D. Little, Inc., estimates.

glass production physically and often are carried out by companies not producing the raw glass. We are not aware of any plate glass production still operating in the United States. The float process glass has replaced plate glass in the market and with the substantial capacity of greater than 1700 x 10^6 sq ft/yr there is now replacement of the double strength sheet glass with float.

In the container industry there are some 130 plants (Arthur D. Little, Inc., 1975) operated by approximately 30 companies. There is a tremendous range of plant capacities and with the advent of triple gobs and greater forming sections, present plants tend towards the large sizes.

Glass fiber plants, of which there are 19 in the United States, vary from 440 x 10^6 lb/yr down to 20 x 10^6 lb/yr (Arthur D. Little, Inc., 1972). The four large plants with capacities greater than 100 x 10^6 lb/yr account for 70% of the total production. Of the 19 plants, 10 use rotary spinners for fiber forming and account for 80% of the production. The remainder of the plants use flame-attenuation.

There are four large textile fiber plants of more than 100 x 10^6 lb/yr capacity. However, most plants are of medium capacity, i.e., 40-50 x 10^6 lb/yr. Both direct melt and marble techniques are used to feed the platinum-rhodium bushings for drawing fiber. Most newer operations use the direct melt approach. By and large, textile fiber plants are multi-product plants producing several types of fiber for different end uses and some semifinished products (see Table A-5).

Soda-lime-silica glasses probably account for 90% of the glass melted in the United States (Arthur D. Little, Inc., 1975). All flat glass, container glass, incandescent lamps and fluorescent lamp envelopes and tubing, and a large fraction of the machine-pressed and blown ware are basically soda-lime glasses with small difference in composition among the different product areas (Table A-6).

Borosilicate glass makes up approximately 2-3% of the glass melted and is used principally in heat-resistant laboratory ware and consumer ovenware. A low-alkali borosilicate is used for producing most textile-grade fiber and glass wool.

Other glass compositions melted are lead glass for electrical applications, optical glasses, and hand-formed artware. It was recently estimated that lead glass represented 0.5% of total glass production. An additional 1% of the glass melted is opal glass, a modified soda-lime-silica.

TABLE A-5

FIBER GLASS PLANTS BY COMPANY AND LOCATION

Company	Textile Fiber Plants	Wool Fiber Plants
Owens-Corning Fiberglas, Inc.	Aiken, S.C. Anderson, S.C. Ashton, R.I. Huntington, Pa. Jackson, Tenn	Barrington, N.J. Fairburn, Ga Kansas City, Kan Newark, Ohio Santa Clara, Cal Waxahachie, Tex
Johns-Manville	Waterville, Ohio	Cleburne, Tex Corona, Cal Defiance, Ohio (3) Parkersburg, W. Va. Penbyrn, N.J. Richmond, Ind Wender, Ga.
PPG Industries	Lexington, N.C. Shelby, N.C.	
Certain-Teed		Shelbyville, Ind. Berlin, N.J. Kansas City, Kan Mountaintop, Pa.
Ferro Corp.	Nashville, Tenn	
(Modiglass Fibers) Reichhold Chem.	Irwindale, Cal Bremer, Ohio	
Fiberglass Industries	Amsterdam, N.Y.	
United Merchants	Statesville, N.C.	
Oliver Glass Fiber	Farmingdale, N.Y.	

TABLE A-6

COMPOSITION OF COMMERCIAL GLASSES BY WEIGHT PERCENT

	Soda-Lime Glass			Borosilicate Glass	Lead Glass
Component	Containers	Plate and Window Glass	Tableware	Specialty Glassware	Specialty Glassware
SiO_2	70-74	71-74	71-74	70-82	35-70
Al_2O_3	1.5-2.5	1-2	0.5-2	2-7.5	0.5-2.0
B_2O_3	0	0	0	9-14	0
Na_2O	13-16	12-15	13-15	3-8	4-8
K_2O					5-10
CaO	10-14	8-12	5.5-7.5	0.1-1.2	0
MgO			4.0-6.5		
BaO	0	0	0	0-2.5	0
PbO	0	0	0	0	12-60

Source: Source Assessment Document No. 3, Glass Manufacturing Plants, Monsanto Research Corporation, for EPA, Contract No. 68-02-1320, November 1974.

3. GLASS MANUFACTURING PROCESS

Although the glass industry produces a large number of different products and serves quite different end-use markets, there are common features in the production process (Figure A-1). The major steps in the process are generally as follows:

- Raw materials batching and handling
- Melting
- Fining
- Forming
- Finishing

Throughout the glass industry, the first three process steps of batch preparation, melting, and refining are quite similar, although refining may differ in degree for different products, such as flat glass, where optical homogeneity is extremely important, and fiber glass, where optical properties are not critical. Batch preparation is not a significant energy-consuming step of the process. However, melting of the raw materials to form a viscous glass melt consumes approximately 70-75% of the total energy used in glass production. The refining step, which homogenizes the melt, accounts for about 5-10%, and forming and finishing, principally annealing, 15%. The remaining energy is consumed in ancillary equipment. Melting and refining are carried out in the large continuous furnace and will obviously receive the greatest attention in attempts to conserve energy through process change.

4. ECONOMIC OUTLOOK

The total value of the production from this industry is about $4 billion. Over the last 5 years, the growth has been at a rate of approximately 3.5% per year, a little less than the Gross National Product. The major factor that dominates the industry's growth is the growth and economics of the principal markets: construction, automotive, packaging, and consumer products. In the last decade, the container glass industry grew significantly as a result of the use of nonreturnable glass beverage bottles. This segment represents about 40-45% of the total output of the industry. Flat glass accounts for about 15% of the industry and fiber glass and pressed and blown glass each represent about 20% of the total output. The total number of plants of any significant size in the industry is approximately 400.

a. Flat Glass*

While sheet glass represents about half the total shipments of flat glass on a surface area basis during the 1968-1972 period, it represents only 32% of total tonnage and 28% of value of shipments (Table A-7). The

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*Arthur D. Little, Inc., 1973.

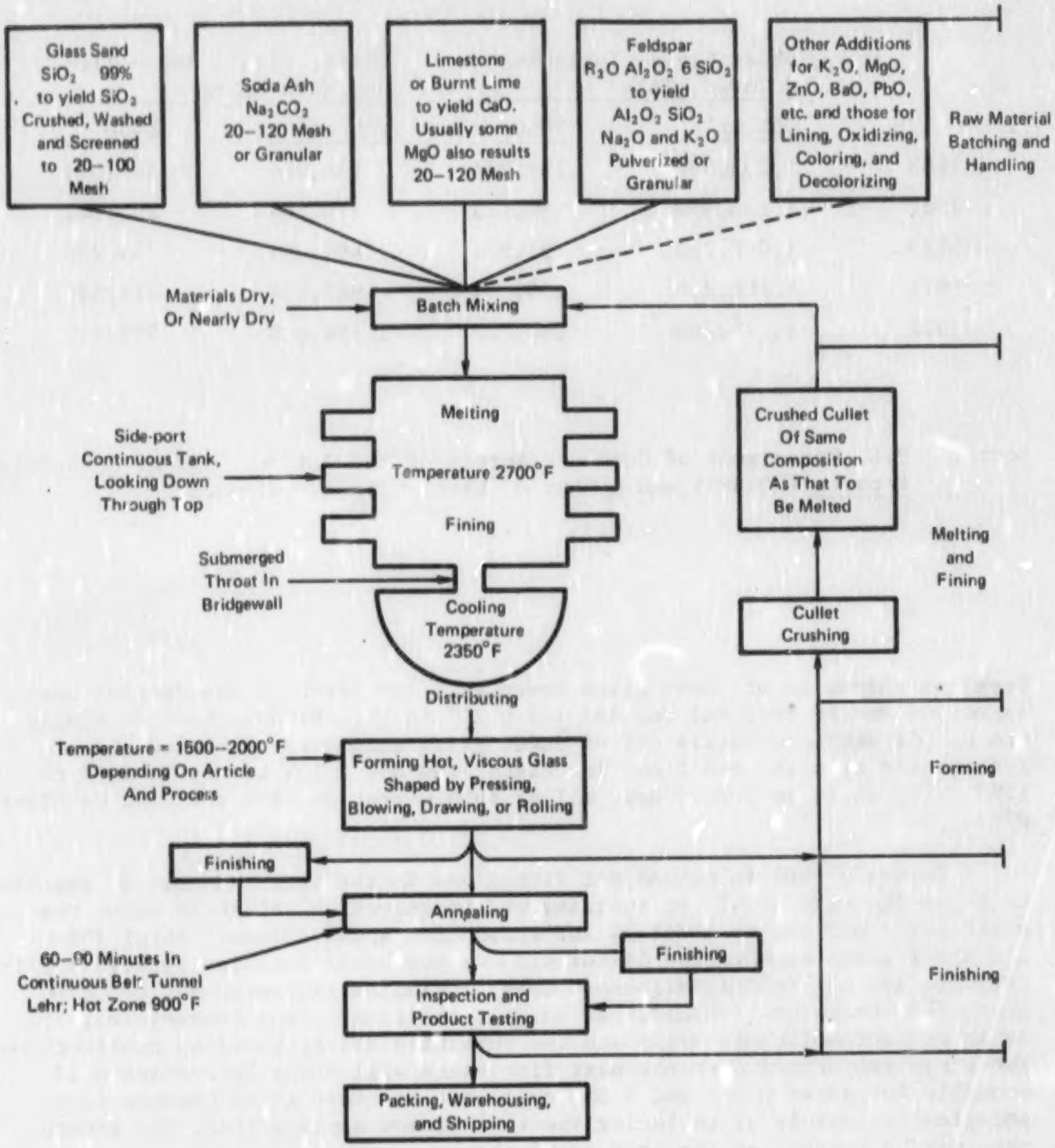
Glass Sand
SiO₂ 99%
to yield SiO₂
Crushed, Washed
and Screened
to 20–100
Mesh
Soda Ash
Na₂CO₂
20–120 Mesh
or Granular
Limestone
or Burnt Lime
to yield CaO.
Usually some
MgO also results
20–120 Mesh
Feldspar
R₂O Al₂O₂ 6 SiO₂
to yield
Al₂O₂ SiO₂
Na₂O and K₂O
Pulverized or
Granular
Other Additions
for K₂O, MgO,
ZnO, BaO, PbO,
etc. and those for
Lining, Oxidizing,
Coloring, and
Decolorizing
Raw Material
Batching and
Handling
Materials Dry,
Or Nearly Dry
Batch Mixing
Melting
Temperature 2700°F
Fining
Side-port
Continuous Tank,
Looking Down
Through Top
Submerged
Throat In
Bridgewall
Cooling
Temperature
2350°F
Distributing
Crushed Cullet
Of Same
Composition
As That To
Be Melted
Melting
and
Fining
Cullet
Crushing
Temperature = 1500–2000°F
Depending On Article
And Process
Forming Hot, Viscous Glass
Shaped by Pressing,
Blowing, Drawing, or Rolling
Forming
Finishing
Annealing
Finishing
60–90 Minutes In
Continuous Belt Tunnel
Lehr; Hot Zone 900°F
Finishing
Inspection and
Product Testing
Packing, Warehousing,
and Shipping

Figure A-1. Glass Manufacture

TABLE A-7

SHIPMENTS OF FLAT GLASS, 1968 - 1972

	Sheet Glass, Including Colored, Total		Plate, Float, and Rolled and Wire Glass	
	000 ft^2	\$000	000 ft^2	\$000
1968	1,095,800	139,391	656,004	248,078
1969	1,160,950	150,123	705,244	266,747
1970	1,069,700	131,551	698,394	253,239
1971	1,188,750	150,344	943,064	314,330
1972	1,196,700	157,222	1,191,830	393,263

Source: U.S. Department of Commerce/Bureau of the Census, Current Industrial Reports (MQ-32A) and Arthur D. Little, Inc., estimates.

level of shipments of sheet glass moved with the level of residential construction and by 1972 had reached 1.2×10^9 sq ft. Window glass in single and double strength totals 84% of sheet glass shipments. Thicker glass, represented by plate and float increased from 656×10^6 sq ft in 1962 to 1192×100 sq ft in 1972. Now, all of this market is also serviced by float glass.

Future growth in demand for flat glass in the United States is expected to be at the rate of 4% for building and construction, slightly below the anticipated GNP and at about 3% for automotive applications. About 70% of the sheet glass consumption is for windows and other building-related applications, and 30% for miscellaneous uses, including laminated and tempered glass for the automotive application. Of the float glass consumption, 65% is in the automotive industry and the remaining 35% in building construction. The projected demand over the next five years will probably average 3.8% annually for sheet glass and 3.3% for flat. As float glass becomes technologically capable of replacing sheet in window applications, its growth rate may be faster, at the expense of sheet.

b. Fiber Glass*

Wool glass fiber (Table A-8) is used primarily for building insulation and acoustical ceiling tile, heating and cooling pipe and duct insulation, and process equipment and appliances. Over the 1964-1971 period that market for glass wool increased at an annual rate of about 7% to 1518 million pounds in 1971. In the same period, sales increased from $227 million to $427 million. In the near term, glass wool fiber growth is expected to average at least 8% annually. This is a higher rate of growth than projected for the U.S. construction industry, primarily because of increased demand for insulation to conserve energy and changing insulation requirements.

The markets for textile fiber glass (Table A-9) are home furnishings, industrial applications, and reinforced plastic. The latter, with 66% of the total consumption, is by far the largest. Home furnishings represent 11% and the industrial applications 20% of this market segment. The use of glass fiber in household furnishings, principally draperies, has reached a high market penetration and further growth will be slow. However the fire-retardant characteristics of glass fiber are responsible for some recent acceleration in the market. In the near term, the home furnishing market should grow at about 5% per year. A major uncertainty in the market is the future of the textile glass fiber business in the vagaries of the automotive tire market. The recent switch to steel radial tires in a large portion of the U.S. auto market indicates that glass belts for belted-bias tires may continue to decrease.

The applications for glass fibers in reinforced plastics are extremely diverse, with the largest end-use markets being marine structures, transportation, principally passenger cars, corrosion-resistant material, and construction. The use of glass fiber in reinforced plastics is expected to be the fastest growing segment of the market with a rate of about 15%; the industrial application market will grow at a lower rate, perhaps 11% per year. Therefore, over the next five years, the total glass fiber market may grow at a rate of 13%.

Historically, the textile fiber glass business has not been a highly profitable one and, considering the rather substantial investment in plant and the high technology required to participate, it is doubtful that substantial expansion will take place. Certainly history has shown that it is difficult for new entries to get into this segment of the industry.

c. Pressed and Blown Glass**

Compared to other segments of the glass industry the pressed and blown segment has had a somewhat better historical growth pattern, particularly the part related to electronics and lighting, which has been growing rapidly over the past decade.

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*Arthur D. Little, Inc., 1972.

**Arthur D. Little, Inc., 1975.

TABLE A-8

U.S. SHIPMENTS AND VALUE OF WOOL GLASS FIBER, 1964-1971

	1964			1965			1966			1967		
Insulation Use	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb
Structural Building	368	76	20.7	438	93	21.1	484	105	22.6	484	109	22.5
Industrial, Pipe & Equipment	570	151	26.5	608	158	26.0	608	173	28.5	554	170	30.7
Total	938	227		1046	251		1072	278		1038	279	
Average			24.2			24.0			25.9			26.9

	1968			1969			1970			1971		
Insulation Use	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb
Structural Building	557	133	23.9	627	158	25.2	644.8	165.6	25.7	--	--	--
Industrial, Pipe & Equipment	567	179	31.6	675	198	29.3	541.5	190.6	35.2	--	--	--
Total	1124	312		1302	356		1186.3	355.8		1518.7	426.9	
Average			27.8			27.3			30.0			28.2

Note: Values are average manufacturers' net selling prices, f.o.b. plant, after discounts and allowances, and excluding freight and excise taxes.

Source: Department of Commerce "Current Industrial Reports".

TABLE A-9

U.S. SHIPMENTS AND VALUE OF TEXTILE GLASS FIBER, 1964-1971

	1964			1965			1966			1967		
	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb	10^6	$\$10^6$	¢/lb
Yarn, Strand, Mat	156.0	83.7	53.7	191.0	101.3	53.0	211.5	116.5	55.1	189.8	100.0	52.7
Roving, Chopped Strand Milled Fiber	73.9	23.8	32.2	95.6	26.7	27.9	116.1	35.2	30.3	118.8	37.5	31.6
Total	229.9	107.5		286.7	128.0		327.6	151.6		308.6	137.5	
Average			46.8			44.6			46.3			44.6

	1968			1969			1970			1971		
	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb	10^6 lb	$\$10^6$	¢/lb	10^6	$\$10^6$	¢/lb
Yarn, Strand, Mat	234.4	121.2	51.7	n.a.	n.a.	n.a.	--	--	--	--	--	--
Roving, Chopped Strand, Milled Fiber	160.1	51.3	32.4	n.a.	n.a.	n.a.	--	--	--	--	--	--
Total	394.5	173.0		477.4	227.4		432.8	192.9		477.6	214.6	
Average			43.9			43.6			44.5			44.5

Note: Values are average manufacturers' net selling prices, f.o.b. plant, discounts and allowances, and excluding freight and excise taxes.

Source: Department of Commerce "Current Industrial Reports".

The machine-made consumer glassware (Table A-10) is the largest single part of this industry segment, accounting for 35% of the total payment and balance value of shipments in 1972. The products are tumblers, stemware, tableware, cookware, ovenware, kitchenware, and ornamental, decorative, and novelty glassware. Tableware and kitchenware make up 46% of the product value. During the 1967-1972 period this business grew significantly, about 65%, equivalent to an annual growth of 10.3%. In that time period, the value of shipments increased considerably faster than the quantity as unit prices increased 30-40%. The outlook is for continued growth in shipments at about the rate of GNP growth. A more rapid increase in value is anticipated as selling prices are increased to reflect increased cost of energy and labor.

Total shipments of glass tubing in 1972 were $55 million, with $40 million, or 73%, accounted for by tubing for fluorescent and neon lighting and the remaining from nonelectrical glass tubing (Table A-11). The growth in dollar value of the industry shipments has been somewhat erratic. Current dollar shipments of tubing for fluorescent and neon tubing have grown at an average annual rate of about 4.5%, while shipments of nonelectrical tubing have grown only 1.8%. The industry's growth is expected to continue to be cyclic because of its close relationship to the construction industry. It appears that there is really no material competition with glass in the major lighting applications; therefore, no major changes are expected in this business.

Light bulb blanks (or envelopes) for incandescent lighting, a portion of the lighting and electronic glassware industry, are specifically covered by SIC Code 3229225. U.S. Department of Commerce Reports lump shipment and value statistics for this industry together with industry 3229235, television tube blanks and parts, and tubing, cane and other glass parts for electronic tubes and devices. In 1972, the total value of shipments for these combined industries was $253 million, of which television tube envelopes and parts accounted for about two-thirds, electronic tube parts about one percent, and electric lamp envelopes the remainder, or about 33%. According to this breakdown, the 1972 value of shipments for electric light bulb blanks was about $84 million. Television tube face plates and funnels were valued at $166 million.

d. Glass Containers*

In terms of unit shipments (which closely approximate industry production), in the past several years the glass container industry has exhibited modest growth, increasing from 253,198,000 gross in 1969 to 266,000 gross in 1972, for an average annual growth rate of 1.8% (Table A-12). The dollar volume, however, has increased considerably more rapidly, as the value per gross increased from $6.08 in 1969 to $7.71 in 1972. Total dollar value of shipments increased by 33.3%, or 10% per year during this period. A trend toward larger containers helps explain this change. The glass container

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*Arthur D. Little, Inc., 1975.

TABLE A-10

SHIPMENTS, EXPORTS, IMPORTS, APPARENT CONSUMPTION: MACHINE-MADE CONSUMER GLASSWARES, 1969-1972

	($000)				
Year	Total Shipments	Exports	Imports*	Apparent Consumption	Imports (% of Consumption)
1969	274,661	20,663	2,319	256,317	0.9
1970	268,749	21,608	2,576	249,717	1.0
1971	326,291	24,776	2,625	304,140	0.9
1972	380,794	29,512**	4,148	355,430	1.2
% Change	+ 38.6	+ 42.5	+ 78.9	+ 38.7	
From 1969 to 1972 Annual Growth Rate (%)	+ 11.5	+ 12.4	+ 21.0	+ 11.5	

* Includes value of product at port of shipment, plus calculated import duty into U.S.A. Imports of machine-made product are assumed to be 5% of total consumer glassware as per U.S. Tariff Commission Report, TC Publication 257, 1968.

** Estimate.

Source: U.S. Department of Commerce Bureau of Census, U.S. Census of Manufactures, 1972.

TABLE A-11

SHIPMENTS OF GLASS TUBING, 1964-1974

Year	Tubing for Fluorescent and Neon Lighting		All Tubing Except Electrical and Electronic		Total	
	$000	% Change	$000	% Change	$000	% Change
1964	28,207	--	13,100	--	41,307	--
1965	31,083	10	13,219	1	44,302	7
1966	36,397	17	17,297	31	53,694	21
1967	33,384	-8	19,123	11	52,507	-2
1968	34,230	3	19,054	0	53,284	1
1969	35,963	5	22,743	19	58,706	10
1970	37,744	5	21,667	-5	59,411	1
1971	38,481	2	15,859	-27	54,340	-9
1972	40,151	4	15,079	-5	55,230	2
1973	45,386	13	(D)	--	--	--
1974	42,958	-5	(D)	--	--	--
Annual Compound Growth Rate 1964-1972 (%)		4.5		1.8		3.9

(D) Withheld to avoid disclosing figures of individual companies.

Source: U.S. Department of Commerce, Current Industrial Reports: Consumer, Scientific, Technical, and Industrial Glassware Series MA-32E.

TABLE A-12

SHIPMENTS, IMPORTS, EXPORTS AND APPARENT CONSUMPTION: GLASS CONTAINERS, 1969-1972

	($000)				
Year	Total Shipments	Exports	Imports	Apparent Consumption	Imports (% of Consumption)
1969	1,636,685	16,292	5,853	1,626,246	0.4
1970	1,830,213	15,079	5,631	1,820,765	0.3
1971	1,922,723	15,173	6,700	1,914,250	0.4
1972	2,055,686	14,982	9,274	2,049,960	0.4
% Change from 1969 to 1972	+25.6	-7.9	+58.5	+26.1	-
Average Annual Growth Rate (%)	+7.9	-3.0	+16.6	8.0	-

Source: United States Department of Commerce, Bureau of Census, Census of Manufactures, 1972.

industry produces a wide variety of products, ranging from perfume bottles to five-gallon water bottles and large carboys. Three types of glass containers, however, account for the bulk: nonreturnable soft drink bottles, nonreturnable beer bottles, food bottles and jars (Table A-13). Combined, these represented almost 75% of all glass containers shipped in 1972.

For the past several years, nonreturnable soft drink bottles have constituted the fastest growing segment of the glass container industry, growing at an average annual rate of nearly 30% in the last half of the 1960's (Table A-14). This type of container grew from 4% of the total glass container shipments in 1954 (on a unit basis) to 23% in 1972. The rapid growth of this product, however, appears to be receding as the nonreturnable bottle has reached a mature stage in its life cycle. Returnable beverage bottles, the main product displaced by the nonreturnables, seem to have reached a point where further declines will be slow. Metal cans, the other major packaging used for soft drinks, will probably show small increases in market share. Currently, nonreturnable glass beverage containers have about 28% of the market; cans have about 35%; and returnable bottles about 37%.

TABLE A-13

DOMESTIC SHIPMENTS OF GLASS CONTAINERS, 1972

Type	(000 gross)	Percent of Total Units (M)	Value (000$)	Percent of Value
Food	82,574	31.2	291,336	17.5
Beverage, nonreturnable	60,954	23.0	461,770	27.7
Beer, nonreturnable	52,705	20.0	265,525	15.9
Medicinal and Health	20,620	7.8	112,473	6.7
Liquor	13,873	5.2	161,394	9.7
Beverage, returnable	10,099	3.8	135,922	8.1
Toiletries and Cosmetics	9,272	3.5	68,815	4.1
Wine	8,552	3.2	120,619	7.2
Household and Industrial	4,282	1.6	35,073	2.1
Beer, returnable	1,699	0.6	11,825	0.7
Dairy Products	238	0.1	4,744	0.3
	264,869	100.0	1,669,496	100.0

Source: U.S. Dept. of Commerce M32 G, (72)-13

TABLE A-14

GLASS CONTAINER SHIPMENTS BY TYPE, 1967-1972
(000 gross)

Type	1972	1967	Percent Change
Food	82,574	81.483	+ 1.3
Medicinal and Health	20,620	22,603	- 8.8
Household and Industrial	4,283	5,664	- 24.4
Toiletries and Cosmetics	9,272	15,913	- 41.7
Beverages, returnable	10,099	13,282	- 24.0
Beverages, nonreturnable	60,954	24,899	+ 144.8
Beer, returnable	1,699	4,332	- 60.8
Beer, nonreturnable	52,705	40,169	+ 31.2
Liquor	13,873	13,752	+ 0.1
Wine	8,552	5,707	+ 49.9
Dairy Products	238	958	- 75.2
TOTAL	269,869	228,766	+ 15.8

Source: U.S. Dept. of Commerce, Bureau of Census, Census of Manufactures, 1972.

In beer packaging, metal cans have been growing rapidly at the expense of glass. From a market share of 58% (including both returnable and nonreturnable) in 1965, glass usage has dropped to about 40% of total beer packaging requirements, and a further erosion is anticipated because of consumer preference for the nonbreakable cans and the industry's desire to take advantage of the ability of cans to be filled more rapidly than bottles.

Glass food containers are the single largest category of glass containers, and are expected to remain so in the foreseeable future. The steady rise in food production, especially in prepared food products, will more than offset anticipated inroads of plastic containers in the food industry.

Glass container use for medicinal and health products, household and industrial items, toiletries and cosmetics, liquor, and dairy products has been either stable or declining in recent years, as plastic containers, aerosols and paper have taken all the growth in these markets. Therefore, we predict that total usage will remain stable.

The glass container industry, aware of its competition from other packaging materials, has been highly concerned with product developments involving product cost, utility, and safety. Significant recent developments have been the resealable twist-off cap for nonreturnable bottles, composite plastic-glass bottles, and the chemical tempering of glass container surfaces for added strength. The resealable bottle cap has prompted a significant shift to larger bottles in the soft drink market.

The glass container business is an extremely competitive, mature industry. Growth in both volume and dollar value of shipments is expected to be at rates significantly lower than GNP growth. From 1973 through 1980, glass container shipments of all types are expected to grow at rates of about 1% per year. Because of shifts in product mix and to higher prices, dollar values will grow by about 4% per year.

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APPENDIX B

ENERGY USE: BASE LINE PROFILE*

1. ENERGY USE BY PROCESS STEP

For purposes of identifying the energy use and intensity by process steps, we added two additional categories - i.e., product handling and space conditioning - to the principal process steps in glass manufacturing (defined in Appendix A). Although the process technology varies considerably depending on the product being produced, these two categories are considered to be similar in all glass manufacturing processes, as are batch handling and melting. Because of special situations, the process difference can influence the distribution of energy in a specific plant. For instance, although the melting function normally consumes 60-80% of the total energy, a fiber glass operation requires large quantities of high-temperature gas to carry out the forming operation. Thus the forming step is more energy intensive than in other glass processing.

The energy consumption by major process step (Table B-1) can vary considerably from plant to plant making identical products. But obviously, the melting of glass is the single greatest consumer of energy in the process. Therefore, it is certainly in this process step that significant changes in energy consumption patterns might be made. We do not suggest that energy savings cannot be made in other process functions: manufacturers are carrying out many modifications and housekeeping improvements to alter energy use. But by virtue of the vast amount of energy consumed in melting glass, this function has become the focus of energy-related process modifications.

Many factors specifically affect the energy use in melting glass: i.e., type of glass, type and size of furnace, method of operation, type of fuel, pull rate, furnace age, and specific construction. Furnaces are designed and constructed on the basis of a single fuel - usually natural gas - and the use of an alternative fuel usually results in a loss in efficiency.

Although batch handling and product handling appear to consume rather consistent portions of total energy regardless of the specific process, space conditioning can vary significantly. Some of these increases in consumption in space heating and cooling are due to such factors as the controlled humidity required in rooms where textile fibers are formed.

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*Battelle Columbus Laboratories, Final Report on Industrial Energy Study for the Glass Industry, for FEA, Contract No. 14-01-0001-1667, December 1974.

TABLE B-1

PERCENT OF TOTAL PLANT ENERGY CONSUMPTION BY INDUSTRY SEGMENT AND PROCESS STEP

Segment	Batch Handling	Melting & Fining	Forming	Post Forming	Product Handling	Space Conditioning
Flat Glass						
Sheet	1.2	75	2.0	2.0	1.3	18.5
Float	1.2	76	5.0	7.0	1.3	9.5
Glass Containers	2.0	70.0	1.5	9.5	2.5	4.5
Pressed and Blown						
Machine Ware	2.0	55.0	15.5	20	7.0	6.0
Lamp Envel., T.V. & Tubing	1.0	65.0	14.0	15	2.0	3.0
Glass Fibers						
Textile	2.0	45.0	28.0	10.0	3.0	12.0
Wool	2.0	40.0	38.0	12.0	2.0	6.0

2. FORM OF ENERGY USED

The six forms of energy used by the glass manufacturing industry are natural gas, electricity, distillate fuel oil, residual fuel oil, propane, and coal (Table B-2). Overall the industry average use is as follows:

	Percent of Total
Natural gas	70.2
Electricity	20.6
Distillate fuel oil	4.6
Residual fuel oil	3.9
Propane	0.3
Coal	0.4

Over recent years, there have been some small shifts in the patterns of use of the above forms of energy. The relative fuel oil consumption has increased and the percent of natural gas has declined, reflecting the supply problem facing the industry. The relative amount of coal used has declined, presumably due to environmental constraints on the use of coal for firing boilers.

Within the various segments, the distribution of energy source use on a percentage basis is not large; however, the largest use of propane and distillate fuel is in the glass container segment. On the other hand, the flat glass segment has increased its use of residual fuel oil. The distribution of natural gas and electricity has remained nearly evenly distributed across the major segments.

Oil and propane are the usual standby, or substitute, fuels for the melting processes. Fuel oil has also been substituted for coal in boilers to make process steam and for space conditioning.

In the United States, natural gas has been used as the primary source of energy for many years: it was a low cost, available, clean, easy to handle fuel. In 1973, it accounted for about 70% of the total energy used in a glass plant. The principal use of natural gas in the integrated glass plant is in the melting function, which consumes 60-80% of the total energy used in a typical glass plant. The specific requirement depends on the product and type of glass. In addition, annealing is carried out as a post-forming operation, and natural gas for this operation constitutes up to 10% of the total plant energy consumption. Natural gas is used for space conditioning, and that non-process function may be as high as 45% of the total, such as in some textile marble melt operations.

TABLE B-2

RELATIVE USE OF DIFFERENT ENERGY FORMS, 1973

Segment	Energy Used %(10^9 Btu)	Type of Fuel (%)	$10^6\ \text{Btu}/\$$ Shipment	10^6 Btu/ton
Flat Glass Sheet Float	20 (65,660)	79. Gas 14.9 Electric 1.1 Coal 6.4 Fuel Oil	63	17.2
Glass Container	48 (155,230)	70. Gas 17. Electric 4. Fuel Oil 7.8 Mid. Dist.	74	13.7
Pressed and Blown	26 (79,920)	69. Gas 25. Electric 3. Fuel Oil 2.6 Mid. Dist.	64.7	43.8
Industry	100	70. Gas 20.6 Electric 3.9 Fuel Oil 4.6 Mid. Dist. 0.3 Propane 0.4 Coal	56,200	

Source: Final Report on Industrial Energy Study of the glass industry, Battelle Columbus Laboratories for FEA, Contract No. 14-01-0001-1667, December 1974.

Fuel oil, either distillate or residual, is a viable alternative fuel to natural gas for melting. But as a replacement, it has limitations: it cannot be used in annealing lehrs or in forehearths. The recent increased use of fuel oil is a direct result of the shortages of natural gas. Historically, the glass industry does not have a strong position if oil allotments are based on past usage.

Electrical energy is used throughout the entire glass plant, primarily for motors for plant heating and cooling and in forming and finishing operations. Of importance is the increased use of electrical energy for melting when, with certain constraints, it is a viable alternative.

Propane is primarily a standby fuel for melting and post-melting operations. Its cost and availability limit broad application except in drastic shortage situations.

APPENDIX C

PROCESSES CONSIDERED

In the analysis of likely process changes in glass manufacturing because of energy cost or shortages, the focus in this study is entirely upon the melting operation. This operation accounts for 60-80% of the energy consumption in a glass plant and, therefore, is the one unit process which offers the industry an opportunity to make any significant change in the energy consumption patterns. In the United States, 85-90% of glass melting is carried out with natural gas. The energy consumption varies significantly from plant to plant because of product differences and furnace type, size and operation.

In the short term, oil will no doubt continue to replace natural gas. Heavy fuel oil is quite acceptable as an alternative to natural gas for melting glass, but special problems require that the sulfur content be no more than 2% and the vanadium (as V_2O_5) content be no greater than 200-400 ppm. The use of oil considerably increases refractory wear, especially with high-sulfur oil. Furthermore, oil flame temperatures and velocities are greater than those of natural gas, resulting in increased NO_x, SO_2/SO_3 and particulate emissions and higher volatization from the glass melt. On the other hand, with oil-firing waste gas heat losses are reported to be lower than with natural gas and oil flame emissivities greater, giving improved melting rates. Some areas of Western Europe have had extensive experience with oil-fired glass melting furnaces and this experience could be a useful source for comparison. This approach is considered fuel switching and not pursued.

Another short-term alternative is the use of electric boosting of fossil-fuel-fired glass melting furnaces. This technique has been useful to increase capacity in existing furnaces without extensive capital expenditures. In gas or oil firing, the heat is transferred from the flame over the glass melt by radiation from the flame and the heated superstructure. Convection currents in the glass melt distribute this absorbed heat throughout the melt depth. In electric melting, the glass melt is heated directly by passing a high current through the conductive glass melt via electrodes inserted in the wall or bottom of the furnace.

The energy introduced by electric boosting is small relative to the total energy input; however, it is utilized at something approaching 100% efficiency. Experience varies with specific installations, but 350-400 kWh of electricity per ton of glass produced has been reported. In a typical operation, electric boosting may increase the furnace output by up to 25%. Increased use of electric boosting would shift the energy consumption to perhaps less critical types of fuel.

Complete electric melting has been used with success in the United States. But, because of the high cost of electrical energy and the present limitation on the size of all electric furnaces, there are relatively few installations. All electric furnaces involve complete new furnace construction and not simply retrofitting, as is the case with electric boosters. The efficiency is claimed to be as high as 80% (~800 kWh per ton) (McGovern, 1972). The surface melt temperatures are low and the volume of waste gases is small; therefore, the air pollution problems are considerably reduced. This is of particular advantage in melting glass containing lead or fluorine. It is not clear if there are technical limitations on furnace size since the much higher tonnage output of these furnaces has not required that furnaces as large as gas-fired ones be built.

Oxygen enrichment has been used by several glass manufacturers (Allen, 1970; Leone, 1973; Leone, 1974) as a means of increasing the pull rate of a glass furnace. The effect of oxygen enrichment is to increase the flame temperature so that a higher melting rate is achieved, hence, more tons per day of glass are pulled from a given furnace. It has been reported that by increasing the oxygen content of the combustion air from 21% to 23% an increase in glass pull rate of about 11% can be achieved, assuming that the number of rejects in the finished product does not change. The purpose in shifting to oxygen enrichment is to increase capacity for short periods of time in order to meet demand with essentially the same equipment and manpower. However, the high flame temperature imposes severe operating conditions upon the refractories, especially the silica crown roof.

The increase in pull rate obtained by oxygen enrichment can also be viewed as a corresponding savings in fuel consumption per ton of glass. This fuel savings is a real energy savings because it takes less energy to produce the required amount of oxygen to raise the oxygen content of the air stream from 21% to 23%.

Assuming that this technology were to be added to current practice, the effect on air pollution control costs would be reflected as an increase in baghouse costs. On a per-ton-of-glass-pulled basis, sulfur emissions will not be altered; NO_x would increase because of the increased flame temperature; and, as indicated above, particulate emissions would be increased. However, there would be no new species of emission that would require changes in the pollution control equipment. Oxygen enrichment would increase baghouse costs by 10-15%.

The principal deterrents to the increased use of oxygen enrichment of fossil fuel firing of glass melting furnaces are the cost of oxygen and the possible effect of the higher flame temperatures on the furnace life. The use of oxygen would appear to be more of an interim solution, and as experience in controlling furnace operating conditions is gained, could be a viable technique to reduce natural gas consumption per ton of glass. Essentially, except for an increase in the cost of pollution control, no additional capital costs are expected for this alternative.

Waste heat from the melting furnace and possibly from other parts of the process could be utilized to preheat the incoming load (glass batch) to the furnace. Depending upon the specific operating conditions, from one-quarter to one-half of the energy to melt glass could be obtained from waste heat. By heating the glass batch outside the furnace, better utilization can be made of the energy. Such a preheat operation is difficult to accomplish without modification of the batch handling methods. Heat transfer to the conventional loose batch is low when the direct exhaust gases simply flow through. Additional problems include the entrainment of some of the small batch particles by the exhaust stream, thereby increasing air pollution problems. Water vapor in the exhaust gases could also condense on the batch and complicate batch handling. Also, the additional length and movement of the batch in such a preheating process would increase the segregation, or demixing, of the batch mix, i.e., separation of the light and heavy particles of the mix.

These complications plus the additional capital investment and space requirements (frequently nonexistent) have precluded the use of batch preheating (Schorr, Battelle) to date. One proposed solution to batch preheating is to convert the glass batch into an agglomerate such as a pellet or a briquette. Once agglomerated, the glass batch can be preheated without the aforementioned problems. While there are a number of technical problems to be solved, in at least one instance a container glass batch was continuously pelletized, dried and preheated to temperatures as high as 1500°F.

Recent work in Japan on agglomerated batch indicated that outputs were increased by as much as 50%. This approach is considered a longer-term alternative to electric boosting, electric furnace, and oxygen enrichment.

Within one segment of the glass industry, flat glass (Arthur D. Little Inc., 1973), the development of the float glass process in the 1950's has resulted in major process changes. Since the introduction of the float glass process, float glass has rapidly replaced plate glass. At first the bulk of float glass had been sold to markets formerly served by plate glass. As the technology developed to the point where glass thinner than 1/4" could be produced by float, not only construction markets but the important automotive glass markets switched to float glass. As of now, the replacement of plate by float glass is essentially complete. The driving force has been the substantially improved economics of the float process in terms of yield, production rate, and lower energy and labor cost.

The tremendously rapid increase in float capacity in the recent past and the planning of new facilities has raised a question concerning the supply/demand of float glass. With the replacement of plate glass by float complete, it is expected that float glass will penetrate the sheet glass market as well. At least one firm has already announced its intention to use an intermediate-quality float glass in its double-strength window glass market now served by sheet glass. The investment in float glass facilities by the major producers - 10 times more than in sheet and plate facilities combined - seems to substantiate the trend.

By and large, the future capacity of the plate and sheet facilities in the United States will probably be governed by economic and marketing factors, including the cost and availability of energy. Although specific data are not available at this time, the phasing out of many old, inefficient sheet glass plants would save energy.

Changes in the feedstock to the furnace could have impact on the energy consumption of the melting process. Glass Container Corp (GCC) claims that by using 60% cullet it can save as much as 1 million gallons of oil each year in the manufacture of 200,000 tons of glass containers (Business Week, March 1975). With 25-30% cullet in the furnace charge the energy savings can amount to 15%. Most glass container manufacturers use 10-15% cullet, and most of this cullet is "house cullet."

Increasing usage of cullet could reduce the need for pollution control equipment. Cullet usage reduces particulate emissions, and GCC claims that at the 60%-cullet level electrostatic precipitators would not be required.

There are, however, several constraints in recycling glass wastes as cullet. Although the glass container manufacturers have supported recycling, to date, post-consumer cullet (cullet obtained from the consumer), on the average, only accounts for 2% of the furnace charge. The cullet is derived from the separate collection of discarded container from recycling centers, dumps, curbside pick-up, etc.

The future availability of post-consumer cullet from mechanical resource recovery systems remains an unknown quantity for the following reasons:

- The high costs of transportation versus the relatively low value of cullet,
- The need for stringent cullet specifications,
- The limited market for clean mixed-color cullet,
- The absence of a commercially operating facility that produces acceptable cullet,
- The high capital investment required to install a glass recovery subsystem, and
- The questionable economics of a mechanical glass-recovery system.

Recycling post-consumer cullet by separate collection has continued to increase each year. In 1974, 2-3% of the glass containers were collected and recycled (Starrett, 1975). Nevertheless, in 1980 no more than about 4% of the glass container production will be recycled by separate collection.

About 30-35 major resource-recovery facilities are in operation, under construction, or in the planning stage in this country. But, many resource recovery operations will not recover cullet because the economics are unfavorable, or they may recover a crude glass fraction for secondary applications, other than glass container manufacture. By 1980, as much as 30,000 tpd of raw refuse could be processed in resource recovery operations with glass subsystems. Taking into account the different efficiencies of the present cullet recovery processes, about 525,000 tons of cullet will be recovered per year. On this basis, cullet recovered from municipal solid waste would amount to about 4% of the glass container shipments (by weight) in 1980.

Today, "house cullet" accounts for 10-15% of the furnace charge, and most glass container manufacturers purchase another 5%. Therefore, if estimates for post-consumer cullet are correct, it is expected that the average glass container manufacturer might use about 20-25% cullet by 1980, instead of 15-20%.

In summary (Table C-1), electric boosting and the substitution of oil and/or propane for natural gas are being used when and where appropriate. (Substitution of oil or propane is considered simple fuel switching and is not considered here.)

TABLE C-1

SUMMARY OF SEVERAL PROCESS MODIFICATIONS CONSIDERED FOR THE MELTING PROCESS

Present or Near-Term Energy-Related Modifications of Melting Process	Potential Melting Process Changes for Future
Oil	Direct fire coal*
Propane	On-site coal gasification*
Increased use of Electric Boosting	All electric melting*
	Batch preheat*
	Submerged burner**
	Oxygen enrichment**
	Recycle cullet**
	Hot gas generator**

*High priority - detailed analysis

**Low priority - qualitative comments

The high priority process modifications are considered to be direct fire with coal, use of coal gasification, all electric melting, and batch or agglomeration preheat. The other possibilities, such as submerged burner, oxygen enrichment and recycling of cullet, may present viable alternatives, but were assigned lower priorities. During this program, another coal-related process, coal-fired hot gas generation, was identified and appeared to have sufficient merit to warrant its inclusion.

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